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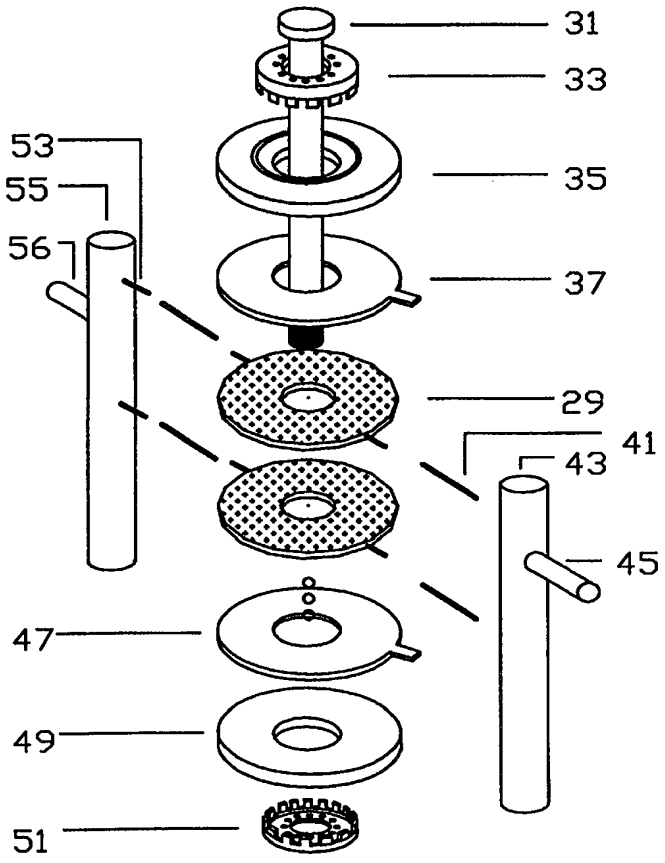
(54) Title: FUEL CELL STACK ASSEMBLY

(57) Abstract

A fuel cell stack assembly (57) includes a plurality of fuel cells (29) stacked upon one another. Each fuel cell (29) includes a membrane electrode assembly (11) having a proton exchange membrane (7) located between the cathode layer (9) and an anode layer (5). The gas distributor (43, 55) is engaged to the membrane electrode assembly (11) to supply gas from a gas supply means to the anode layer (5). The cathode side (17) of each fuel cell (29) may include a plurality of passages for allowing oxygenated gas to pass therethrough and over the cathode layer (9) of the particular fuel cell (29). The gas distributor (43, 55) may comprise an enclosure (63) which surrounds the outer edge of the anode layer (5) of the fuel cell (29) for a plate which faces the anode layer (5) of the fuel cell (29).



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FUEL CELL AND STACK ASSEMBLY

Field of Invention

The present invention relates to Polymer Electrolyte Membrane (PEM) fuel cells and in particular, to the construction of fuel cell stacks, a device containing multiple fuel cell assemblies, for ambient temperature and humidity operation.

Background of Invention

A PEM fuel cell device generates electricity directly from fuel source such as hydrogen gas and an oxidant such as oxygen and air. Since the process does not "burn" the fuel to produce heat, the thermodynamic limits on efficiency are much higher than normal power generation processes. In essence, each fuel cell consists of two catalytic electrodes

separated by an ion-conducting membrane.

The chemical reaction that takes place within a PEM fuel cell is the joining of molecular hydrogen and oxygen to form water vapor and some heat. The reaction, can be simplified to three basic steps. First a fuel gas, hydrogen is oxidized: $2H_2 \rightarrow 4H^+ + 4e^-$. The electrons are collected and then allowed to go through an external circuit where they do some useful work. The positively charged protons from the reaction are drawn into the cell. The positively charged protons go through the cell because of an electrical potential formed due to the second step in the chemical reaction. In the second step, the oxygen is reduced using the electrons returned to the cell from the external circuit: $O2 + 4e^- \rightarrow 2O^{2-}$. The third step in the reaction is for two protons, that passed through the cell , to join up with each oxygen ion, O^{2-}, to form water: $4H^+ + O^{2-} \rightarrow 2H_2O$. The water comes out as vapor initially and will only form liquid water if the vapor comes in contact with a surface that is cold enough to allow it to condense. The oxygen reduction process generates some heat as a byproduct and the condensation of water if allowed to take place within the cell will also add some heat.

The oxidation and reduction steps physically take place on a catalyst surface. The catalytic surfaces are arranged on the opposite sides of a thin membrane. The membrane keeps the fuel gas and oxidant gas separated and allows the protons to be drawn through

by the electrical potential, which has formed during the chemical reaction. The membrane is an electrical insulator and does not allow the electrons to pass through. The electrons, which are necessary to complete the chemical reaction, must then pass through the external electrical circuit.

Historically PEM fuel cell technology has not been economically successful due to the high cost of fuel cell materials, the operating conditions necessary for stable operation, and the fuel cell and stack architecture. The fuel cell stack, a device containing multiple fuel cell assemblies, have employed designs and materials which have made the technology unaffordable.

The traditional fuel cell stack architectures have to sustain the operating conditions necessary for stable operation. These requirements were high-pressure operation in the range of three to five times the normal atmospheric pressure, operating temperatures above 80 Degrees Centigrade, and reactant gases whose relative humidity were one hundred percent. These requirements drove the designs to utilize graphite or graphite composites as the cell support hardware. These materials are inherently expensive and need high precision machining steps to bring them to the required form. The pressure requirement meant that the cell hardware had to be robust enough to restrain the pressure. The cells, making up the stacks, were held together with heavy

compression plates and peripheral bolting schemes.

The advent of new hydrocarbon fuel cell materials which do not require the same operating conditions as the previous generations have relaxed the requirements on the fuel cell and stack design. The new hydrocarbon materials can be operated at ambient pressure and at lower than 50 Degrees Centigrade. In addition they do not require the reactant gases to be at one hundred percent relative humidity.

It is an object of this invention to construct fuel cell stacks, which are inherently low in cost and simple to assemble. These stacks will make use of low cost materials such as commonly available engineering plastics and stainless steel. The materials will be formed to their final shapes with high productivity processes such as stamping and injection molding avoiding the use of high cost, low productivity, and precision machining steps.

Summary of the Invention

The invention comprises a combined fuel cell and stack architecture that allows for the building of low cost stacks which are easily assembled. The fuel cell and stack component designs are made of common materials, which do not require expensive and time consuming precision machining steps. Each cells consist of six components including the Membrane Electrode Assembly. The cell architecture allows for very close vertical spacing of cells and is scalable

from a very small active area cells to very large active area cells. The stack consists of three additional components, which provide the cells with the fuel gas and oxidant and complete the electrical circuit. The fuel cell and stack architecture can easily be modified for passive or active oxygenation airflow and is compatible with several air and water cooling schemes.

The fuel cell stack assembly according to the present invention may include a plurality of fuel cells, each fuel cell contains membrane electrode assembly having a proton exchange membrane located between the cathode layer and the anode layer. A gas distributor is engaged to the membrane electrode assembly to supply gas from the gas supply means to the anode layer. The membrane electrode assembly and the gas distributor form an anode side and a cathode side of a fuel cell. The first fuel cell is stackable upon another fuel cell and forms a space therebetween to pass through the oxygen containing gas. The fuel cells are capable of using an electric current between the cathode when gas is supplied from the gas distributor to the anode.

The cathode side of a fuel cell may include a plurality of passages for allowing oxygenated gas to pass therethrough and over the cathode layer. The gas distributor may be configured to supply gas to an outer edge of the anode layer when gas flows from the outer edge of the anode layer over the anode layer.

The gas distributor may include an enclosure which surrounds the cathode and anode layer, and the enclosure may include one or more openings to support the anode layer to supply gas thereover. The enclosure may include a gas inlet port and gas outlet port leading to the one or more openings. The gas inlet ports may be in fluid flow relationship with the gas supply means. The enclosure may include a gas distribution port positioned to supply gas to a second enclosure on a second fuel cell from the first fuel cell is stacked with the second fuel cell to supply gas to the anode layer of the second fuel cell.

Alternatively, the gas distributor may include a plate having a side facing the anode layer and one or more openings to allow the gas to flow over the anode layer. The plate may include a plurality of grooves on the side facing the anode layer.

The first fuel cell and second fuel cell may include a hole located transversely thereto for allowing oxygenated gas to flow therethrough. A fan may be positioned to force air through the hole. The cathode material may be placed over the cathode layer to allow oxygenated gas to flow therethrough.

Brief Description of the Drawings

FIG. 1 depicts an isometric view of the components of a single fuel cell removed from one another but in their order of stacking useable in the radial air stack design of the present invention;

FIG. 2A, 2B and 2C depicts a bottom side and top view, respectively, of the bipolar plate shown within the single fuel cell of FIG. 1;

FIG. 3 depicts a schematic representation of the single fuel cell assembly process useable in the radial air stack design of the present invention;

FIG. 4A and 4B depicts both an exploded view and an assembled view, respectively, both isometric, of an assembled radial air stack having multiple fuel cells therein constructed in accordance with the principles of the present invention;

FIG. 5A and 5B depicts both an exploded isometric view in both the unassembled and assembled form of the radial air stack of the present invention having multiple fuel cells with an enclosed barrel fan therein;

FIG. 6A, 6B and 6C depict schematic representations of passive non-driven air flow through the radial air stack of the present invention, active driven air flow, and the barrel fan active driven air flow, respectively;

FIG. 7A and 7B depict an unassembled exploded view of a single in-line membrane electrode assembly cell, as well as an assembled view of the same, respectively;

FIG. 8A and 8B depict an assembly stack made with multiple in-line membrane electrodes as depicted in FIG. 7 including the air flow assembly apparatus in an unassembled exploded view, as well as an assembled

view, respectively; and

FIG. 9A and 9B depict a single modified radial fuel cell in an unassembled exploded view, as well as an assembled view, respectively;

FIG. 10A, 10B and 10C depict a finished membrane-electrode assembly in assembled form, and unassembled membrane-electrode assembly, and an electrode membrane-electrode assembly;

FIG. 11A and 11B depict one embodiment of a finished assembled fuel cell, as well as a schematic representation of an unassembled fuel cell, respectively;

FIG. 12 depicts a schematic representation of an unassembled fuel cell stack assembly containing the fuel cells depicted in FIG. 11A;

FIG. 13 depicts a finished fuel cell stack assembly containing the fuel cells depicted in FIG. 11A;

FIG. 14A and 14B depict an assembled SIM fuel cell assembly, and an unassembled SIM fuel cell assembly, respectively;

FIG. 15 depicts an unassembled view of a SIM stack assembly including the SIM fuel cell depicted in FIG. 14A;

FIG. 16 depicts a SIM fuel stack assembly including a SIM fuel cell depicted in FIG. 14A;

FIG. 17 depicts a schematic representation of the air flow through a thin fuel cell of the assembled finned fuel cell assembly is depicted in FIG. 16;

FIG. 18 depicts a schematic representation of the air flow through a SIM fuel cell stack assembly which includes cooling plates for improved cooling; and

FIG. 19 depicts a groove pattern contained within the hydrogen manifold in the stack fuel cell assembly of FIG. 11-FIG. 18.

Detailed Description

An approved ion conducting fuel cell membrane for use in the present invention is disclosed in U.S. Patent Number 5,468,574, issued on November 21, 1995 and assigned to The DAIS Corporation of Palm Harbor, Florida, U.S.A. An approved low cost Proton Exchange Membrane ("PEM") fuel cell electrode also for use in the present invention is disclosed in U.S. Patent Appln. Ser. No. 08/673,661 filed on June 25, 1996 and also assigned to The DAIS Corporation. The specifications of U.S. Pat. No. 5,468,571 and U.S. Patent Appln. Ser. No. 08/673,661 are hereby incorporated by reference and made a part of the disclosure herein.

Referring to Figure 1, a radial air flow fuel cell 29 is shown. The first part in the radial flow fuel cell is the bipolar plate 1. Referring to Figures 2A-C, the Bipolar plates are cut from a thin sheet of plastic, are double side lapped flat and are CNC milled to produce the cathode air side 17 radial groove pattern and the anode hydrogen side 19 circular feed groove pattern. When the bipolar plates are

aligned on top of one another, the cathode air side 17 allows air to enter from the edge of the plate and exit through the center opening in the bipolar plate while the anode hydrogen side 19 distributes the hydrogen fuel gas evenly from a single feed point to the entire area of the anode of the fuel cell. Small holes (not shown) are drilled from the edge of the plate which intersect with holes drilled at specified points in the circular hydrogen side 19 flow pattern. The small holes drilled in the edge allow the insertion of small stainless steel tubes 18 therein and into the side of the plate 1. These tubes allow the hydrogen gas to enter and flow up into the anode hydrogen side circular flow pattern 19. At the same time any trapped air to able to leave the anode region from the access holes drilled on the opposite side of the bipolar plate 1. The bipolar plates 1 are completely plated with three layers of metal which include a strike layer of copper, followed by a thick layer of electroplated copper, followed by a thin layer of impervious corrosion resistant nickel. The bipolar plate 1 is to be joined to the Membrane-Electrode Assembly, ("MEA") shown in Figure 1.

Referring to Fig 3, a schematic representation of the radial fuel cell assembly process is shown. First, a laminated membrane-electrode assembly 11 is bonded to a bipolar plate 1 using a groove bead 3 to result in a sub-assembly 23. The sub-assembly 23 is attached to the bipolar plates 1 to form a portion of

the fuel cell 25. Shims or spacers 13 and cathode screen 15 are placed on top of the portion 25 to result in a complete fuel cell 29.

Referring to Figure 1, the membrane-electrode assembly 11 of the fuel cell 29 is made up of three pieces. The first is the anode electrode 5. The electrode structure is described in the Patent Application Serial Number 08/673,661 filed on June 25, 1996 and incorporated herein by reference. The second piece is an ionic conducting membrane 7. The membrane 7 is described in U.S. Patent No. 5,468,574 that was issued on November 21, 1995 and is also incorporated herein by reference. The third piece is the cathode electrode structure 9 which is again described in Patent Application Serial Number 08/673,661 filed on June 25, 1996. The electrode typically includes (a) an electronically conductive porous body in electrical contact with (b) a catalyst layer comprising (i) a catalyst dispersed on the surface of a carbon support; (ii) a water-insoluble sulfonated polystyrene, sulfonated poly(α-methylstyrene) or sulfonated styrene-ethylene-butylene-styrene (SEBS) block copolymer; and (iii) a nonionic fluorocarbon polymer. Preferred sulfonated polystyrenes, poly(α-methylstyrene)s and SEBS's have a conductivity of 0.04 S/cm or greater, a molecular weight from 30,000 to 1,000,000, and are 10 to 60 mole percent sulfonated. The term water-insoluble refers to polymer electrolytes whose solubility in water at 23°C is less

than 15% by weight. In a preferred embodiment, the sulfonated polystyrene is 25 to 45 mole percent sulfonated polystyrene of molecular weight 200,000 to 400,000. The nonionic fluorocarbon polymer may be chosen from the group consisting of poly(tetrafluoroethylene), poly(vinylidene fluoride), poly(tetrafluoroethylene-hexafluoropropylene), poly(hexafluoropropylene oxide), and poly(tetrafluoroethylene-hexafluoropropylene oxide). Particle sizes from 0.05 μm to 500 μm are preferred. The catalyst may be chosen from the group consisting of platinum, palladium and binary and ternary mixtures and alloys of platinum and palladium with Group VIII metals. Preferred catalysts are Pt, Pd, Pt-Ru and Pt-Co-Cr.

A preferred embodiment of the electrode may comprise: (a) a porous carbon fiber sheet having a hydrophobic binder and a porosity of 30 to 70% in electrical contact with (b) a catalyst layer comprising (i) a platinum or palladium metal catalyst dispersed on the surface of a particulate carbon support at 5% to 30% by weight of the carbon support; (ii) a sulfonated polystyrene of molecular weight from 200,000 to 400,000 sulfonated to 25 to 40 mole percent; and (iii) from 15 to 30% of the total weight of the catalyst layer of a particulate poly(tetrafluoroethylene) of particle size from 50 μm to 500 μm.

A membrane of a proton-conducting polymer is

located between a first and second electrode and in contact with both. In a preferred embodiment the proton-conducting polymer membrane is a sulfonated styrene-alkylene block copolymer, preferably a sulfonated styrene-(ethylene-butylene)-styrene triblock copolymer (SEBS), and the styrene component is sulfonated to the extent of at least 25 mol%. The catalyst layer preferably comprises (i) a platinum or palladium catalyst dispersed on the surface of a particulate carbon support, (ii) a sulfonated polystyrene of molecular weight from 200,000 to 400,000 sulfonated to 25 to 40 mole percent; and (iii) from 15 to 30% of the total weight of the catalyst layer of a particulate poly(tetrafluoroethylene) of particle size from 0.05 μm to 500 μm.

The electrode may be made by a) applying a suspension of 40 to 80 parts of catalyst-coated carbon particles plus 5 to 20 parts of particulate poly(tetrafluoroethylene) in 1200 parts of water to a particulate carbon paper having a hydrophobic binder and a porosity of 30 to 70% to provide a catalyst-coated carbon support; (b) heating the catalyst-coated carbon support in an inert atmosphere at an increasing temperature from 125°C to greater than 250°C; (c) cooling the catalyst-coated carbon support in an inert atmosphere to a temperature below 125°C; (d) applying a 5% by weight solution of sulfonated polystyrene in a solvent having a boiling point below 125°C; and (e) drying the catalyst-coated carbon support until less

than 10% solvent remains and the catalyst-coated carbon support contains from 0.2 to 2.0 mg/cm^2 of sulfonated polystyrene.

The electrodes may be employed in the fuel cell element by (a) preparing two porous gas diffusion electrodes as above; (b) providing a proton-conducting polymer membrane comprising a styrene-(ethylene-butylene)-styrene block copolymer (SEBS), the styrene component being sulfonated to the extent of at least 25 mol%; and (c) laminating the two electrodes to opposite faces of the membrane by heating at a temperature and pressure for a period of time sufficient to provide mechanically stable junctions on both faces of the membrane.

The cathode and anode electrodes may be made of a carbon cloth or stainless steel. The cathode electrode 9 and membrane 7 are slightly larger in diameter than the anode electrode 5 so that when the three pieces are laid up on top of one another there is an exposed membrane area around inner and outer periphery of the annular form. Once the parts are aligned on top of one another the Membrane-Electrode assembly ("MEA") 11 is laminated together using elevated temperatures and pressures. The lamination takes place in an alignment fixture (not shown) which uses the edge of the three pieces to determine the center point of each piece. The alignment fixture is then placed between two flat ground plates. The plates are used to apply pressure to the top of bottom

of the MEA assembly 11 when the entire assembly is placed in a heated platen lamination press. A modest clamping pressure is applied first to let the assembly warm up to lamination temperature of 50°C as measured by the temperature in the top plate, read by a thermocouple. Once the lamination is reached, the full lamination pressure of 750 psi is applied for one minute. After the lamination step, the alignment fixture and plates are removed from the lamination press and allowed to cool for several minutes before breaking down the assembly and removing the laminated MEA 11. Due to the nature of the ionic membrane the assembly bonds together permanently forming, the laminated MEA 11. The laminated MEA 11 is then joined to the bipolar plate 1.

Referring to Figures 1 and 3, the bipolar plate 1, laminated MEA 11 joining process is shown. First the bipolar plate 1 has glue 3 applied to special groves which have been milled into the plate along the inner diameter and outer diameter of the top side (Figure 2). The glue bead 23 and the laminated MEA 11 is aligned on top of the prepared bipolar plate with the exposed membrane area face down (anode electrode) to mate with the glue on top of the plate. A slight pressure is applied to seat the laminated MEA 11 onto the bipolar plate 1. The glue is then cured with heat and/or ultraviolet radiation to form a permanent bond as shown in Figure 3. The final steps to forming the radial flow fuel cell 29 are to place the stainless

steel shims or spacers 13 and cathode stainless steel screen 15 on top of the assembly. The radial flow fuel cell is now complete and is ready to be placed into a stack. The resulting cell is extremely compact and allows 8 to 12 cells per vertical inch.

Referring to Figure 4A and 4B, the process of assembling a radial air stack is shown. The process starts by placing the bottom air threaded access nut 51 on a flat surface. The air access nut is designed with slots along its edge, a hollow interior, and holes along its top surface to let air flow freely into an out of the center opening in the radial air stack despite the presence of the compression center bolt 31. Next the bottom plastic pressure diffuser 49 is placed on top of the nut followed by the bottom current collector 47. The pressure diffuser takes the force applied by the air access nut and distributes the force evenly over the entire annular area of the cells. A pressure diffuser is located on top and bottom of the stack to produce a balanced force to compress the cells. The top current collector 37 and bottom current collector 47 form the electrical interface to the outside electrical circuit. These collectors are preferably made from 316 stainless steel as are all the plates and wire cloth screens. They collect the electrical current from the top of the stack, allow it run through the electrical load, and then distribute it back to the bottom of the stack. The next items to go into the assembly are the

fuel cells themselves. Any number of fuel cells 29 may be placed in the stack but 10 or 20 cells are normally employed. The cells are aligned so that their gas inlet and outlet tubes 18 and 20 are aligned on top of each other respectively. After the final cell is placed on the stack, the top current collector 37, top plastic pressure diffuser 35, top air access nut 33 are put in place. Finally the compression center bolt 31 is placed down the center of the stack and is threaded into the bottom air access nut 51 and the assembly is tightened down. The central compression bolt approach to the assembling the stack eliminates the peripheral bolting schemes commonly employed in other stack designs. The stack is lighter and smaller because of the cell and central bolt compression scheme. The next steps are to connect the hydrogen gas distribution system to the stack.

The gas distribution system consists of two external manifolds 43, 55; one manifold distributes the hydrogen gas into the stack 56 and the other manifold 43 collects the air that must be purged from the anode grooves 19 of the bipolar plate 1. A fuel cell will not start to function until the oxygen and nitrogen in the air have been eliminated from the anode electrode region. The hydrogen manifolds are hollow tubes whose ends have been block by threaded screws and into which small holes have been drilled at regular intervals. Into these small holes, small interface tubes 52 are placed. The small interface

tubes have a larger outer diameter than the holes so there is an interference fit which seals the tube into the hole. Plastic connection tubes form the joint between the manifolds and the bipolar plate inlet and outlet tubes 18 and 20. Large inlet and outlet tubes 45 are placed in the manifolds to get the hydrogen gas into and the air out of the manifolds. The manifold diameters are sized such that the total interface tube area is less than 1/10 of inner diameter area of the manifold to prevent any flow induced pressure drop inside the manifold itself. The assembled radial air stack 57 is shown in Figure 4.

The operation of the stack will now be described. A pressurized gas cylinder with a regulator attached is connected to the hydrogen inlet manifold. The operating pressure of the stack is nominally 2 Psig but can go as high as 10 Psig. The gas cylinder valve is opened pressurizing the inlet manifold 45, the anode area of each cell, and the exhaust manifold 43. The pressure in the anode is opposed by the spacer shims 13 and annular cathode screen 15 backed up by the top and bottom compression diffusers 35 and 49. The purpose of spacer shims 13 is to apply extra pressure to glue area of the bipolar plate to prevent the 2 Psig pressure from lifting the glue bead and generating a leak. The cathode screen also provides electrical contact to the cathode of each cell allowing continuity between that cell and cell below it in the stack. The screen also allows the maximum

amount of area to be open to the air. The cathode electrode consumes oxygen from the air and rejects the water that forms in the electrochemical reaction that generates the electricity. A second valve connected to the exhaust manifold outlet tube 45 is opened briefly allowing the trapped air in the anode area of the stack to be purged along with some of the hydrogen from the cylinder. The second valve is closed and the pressure now builds up again in the stack. In each anode area of each cell, the hydrogen begins to oxidize providing electrons to other cells and the external electrical circuit. The stack is now activated and will show a high voltage called an open circuit voltage, but no current will flow until the external circuit is connected. Once the external load is connected, the cathode side of each cell will begin to reduce oxygen from the air. Each cell in the stack provides the electrical current for the cell below it. The final cell at the bottom of the stack provides the current to the external circuit which is then returned through the load to the top cell in the stack. The external load resistance determines how much current will flow from the stack to the external circuit. The lower the load resistance the more current will flow. The oxidized hydrogen from the anode now begins to flow across the membrane in each cell and join with the reduced oxygen from the air to form water. The stack is now self regulating. The stack will consume only as much hydrogen as necessary to satisfy the

current which is determined by the external circuit resistance. The cathode electrode will consume oxygen from the air as needed to keep the current flowing and will reject the water that is formed either as vapor or as liquid droplets.

The annular design of the radial air flow stack 57 (Figure 4B) allows even uniform 360 degree access of air to the cathode cell surfaces to sustain the reaction. The air flows into the stack along the radial grooves and oxygen diffuses through the cathode screen into the electrode. A second byproduct of the reaction is waste heat. As the interior of the stack warms up a convection current forms along the central cavity increasing the flow of air along the radial grooves that run along the bottom of each cell's bipolar plate. This central cavity acts as a chimney and pulls additional air from the bottom of the stack through the air access nut. Thus the waste heat from the stack is utilized to increase the operation of the stack. This is called passive air flow operation and the air flow pattern 62 is shown in Figure 6.

Other types of air operation are possible. The limiting factor on the power output of the radial flow air stack is the availability of oxygen from the air. The stack output can be enhanced by a factor of three over passive mode operation if a forced air flow is employed (Figure 6B). The stack is placed in an enclosure with three openings. The first opening allows the air access nut on top of the stack to be

extended outside the enclosure while the second opening is along the bottom of the enclosure allowing the bottom air access nut to likewise extend outside the enclosure. The third opening has a fan 63 placed over it. As the fans spins, air is forced into the enclosure. The only way for the air to exit the enclosure is to flow along the groves on the bottom of each cell's bipolar plate, into the central cavity, and out through the air access nuts. The resulting air flow pattern is shown in Figure 6. The rate of air flow is controlled by the fan rpm and is matched to the current generated by the stack by a small microprocessor which monitors the stack operation. Power to run the fan and microprocessor is derived from the stack itself. In order to eliminate the need for a starter battery, the stack operates in passive mode to during startup. The radial air stack also solves another problem with fuel cell operation. Active air flow fuel cell stacks typically have problem operating at very low power ratings because the air flow tends to dry out the cathode when there is not much current running through the external circuit; i.e. not much water is being generated. The radial air stack design allows for the fan to be shut off when the stack is operating below 15% of its rated maximum power. Thus the active air flow design allows for passive operation as well.

A third mode of operation is also possible. In order to eliminate the enclosure it is possible to

place a fan in the central cavity as shown in Figure 5A. A barrel fan 60 is mounted around the central compression bolt and driven by a gear 59 which is connected to an offset external drive shaft 58. The top air access nut design is modified to accommodate both the drive gear and drive shaft. The bottom air access nut is essentially unchanged except for an insert to accommodate another drive gear which is used only to align the barrel fan in the central cavity. The resulting air flow pattern is shown in Figure 6. This design allows the radial air stack of overcome another problem with fuel cell stacks. In very large high power stacks, getting rid of the waste heat generated becomes the operational constraint which limits power output. The problem results because the ability of air to carry moisture goes up exponentially with temperature. As the stack temperatures rise above 45 degrees centigrade the amount of air that the stack requires to carry away the excess water goes down while the amount needed to carry away the heat goes up. It is not possible to operate air breathing stacks above 45 degrees centigrade without inserting cooling plates between each cell in the stack because of this fact. The cooling plates must be supported by an external cooling subsystem to force a cooling liquid through each of the cooling plates. This requires pumps and other support equipment. The radial active air flow design with a central cavity fan overcomes this

problem. The design allows two air flows to exist independently. The first flow is the through the stack and is controlled by the central cavity barrel fan. The second flow is routed around the outside of the stack and is generated by a second fan. Thus large high power air breathing stack can operate at 45 degrees centigrade and above with this design.

The final item to be discussed is the shutdown of the stack. First the load is disconnected from the stack stopping the current flow. The valve on the pressurized cylinder is turned off. The pressure is then released from the system by opening the purge valve attached to hydrogen exhaust manifold. The cylinder is disconnected from the input hydrogen manifold. The open circuit voltage will persist on the stack as long as their is a concentration of hydrogen fuel is the anode area of each cell. Oxygen and nitrogen from the air will diffuse in through the connections to the hydrogen manifolds. As oxygen enters the anode area it combines with the remaining hydrogen on the anode electrode surface to form water. As the hydrogen is consumed this way, the open circuit voltage fades to zero.

In another aspect of the invention, the fuel cell may be configured as a single in-line MEA ("SIM") cell stack which has a very simple rectangular design which glues together from a series of easily fabricated parts consisting of an injection molded plastic enclosure and stamped stainless steel wire cloth

screens and plate. Referring to Figure 7A and 7B, a single SIM cell multi-part assembly 85 is shown. One component of this assembly is MEA enclosure 71. This part can be thought of as a window frame which functions as an edge stiffener. This part, simple in design, may be injection molded from common engineering plastics. The membrane electrode assembly 77 fits inside the enclosure and is glue sealed to a lip on the top face of the frame.

The SIM MEA rectangular assembly 77 is created in the same way as the annular radial air MEA assembly depicted in Figures 1-6. The assembly is made up of three pieces. The first is an anode electrode (similar to electrode 5 of Figure 1) and is now rectangular rather than annular. The electrode structure is described in U.S. Patent Application Serial Number 08/673,661 that was filed on June 25, 1996. The second piece is an ionic conducting membrane (similar to membrane 7 of Figure 1) and is again rectangular rather than annular. The membrane is described in U.S. Patent No. 5,468,574 issued on November 21, 1995. The third piece is the cathode electrode structure (similar to cathode electrode 9 of Figure 1) which also is now rectangular rather than annular. The cathode electrode structure is described in U.S. Patent Application Serial Number 08/673,661 filed on June 25, 1996. The cathode, anode and membrane are joined together as described previously herein with regard to the radial air stack to form the

rectangular membrane electrode assembly 77 shown in Figure 7. The anode electrode and membrane are slightly larger than the cathode electrode so that when the three pieces are laid up on top of one another to form the MEA 77 there is an exposed membrane area around outer periphery of the rectangular form as is shown in Figure 7A. Once the MEA parts are aligned on top of one another the assembly is laminated together using elevated temperatures and pressures as previously described. Due to the nature of the ionic membrane the assembly bonds together permanently forming, the laminated MEA 77 (which is equivalent in structure to MEA 11 in Figures 1 and 3) but is rectangular rather than circular. As is shown in Figures 7A and 7B, MEA 77 is then joined to the MEA enclosure 71.

The laminated MEA 77 has glue 75 applied to the exposed membrane area that is on the outer periphery of the laminated structure. This glue coating is be extremely thin and is brushed on. Alternatively the glue can be applied to the lip of the enclosure and will still achieve the same result. As the enclosure and laminated MEA 77 are joined, the cathode electrode fits through the rectangular opening in the enclosure 71. The glue is then cured with ultraviolet radiation and or heat to fuse the parts together and forming a gas tight seal.

The MEA enclosure 71 incorporates hydrogen inlet and outlet pipes 69 and 71. These pipes are injection

molded when the enclosure is formed. The pipes 69, 71 are circular but non-circular or oval tube geometries may also be used. Inserted into the enclosure behind the MEA is a piece of stainless steel wire cloth 79. The wire cloth functions as a electrical current pickup and gas distribution media to the anode of the MEA 77. A stainless steel shim plate 83 is glued to the bottom face of the frame using a glue pattern 81. The glue bead 81 can be applied either to the enclosure or to the plate. The glue is then cured with ultraviolet radiation or heat to fuse the plate to the rear of the enclosure forming a gas tight seal. The assembled components 69, 71, 73, 75, 79, 81, 83 form the anode environment of the fuel cell 85 and allow the injection of pressurized hydrogen gas into the anode side of the MEA 77. An additional benefit of the design is the pressure from the hydrogen gas reinforces the gas seal on the MEA because of force that the gas applies to the anode of the MEA.

The final pieces of the SIM cell design can now be added to the assembly. cathode screen 67 and cathode screen 65 are placed on top of MEA enclosure. Cathode screen 67 makes electrical contact to the cathode of the assembly yet leaves the surface exposed to oxygen from the air. Cathode screen 65 functions a oxygen diffusion enhancer. The open areas in the zig zag design allow air to travel freely across the almost the whole surface of the cathode. The oxygen from the air will then diffuse through cathode screen 67 to the

surface of the cathode and react. The final assembled form of the SIM cell is shown in 85. The resulting cell is again extremely compact and allows 8 to 12 cells per vertical inch. The freestanding cell assemblies can also be individually tested prior to being placed into the stack. This is an important manufacturing advantage because it eliminates having to disassemble and reassemble the stack if there is bad cell. The SIM cell is now ready to be incorporated into a fuel cell stack.

The process of assembling a SIM stack is shown in Figure 8A and 8B. The process starts by placing the bottom compression plate 111 on a flat surface. The bottom compression plate is made from plastic and can be machined or injection molded from engineering plastics. The plate has four threaded holes as shown in the drawing. The threads in the holes can be formed in the plastic itself or be created via the use of a metal press fitted insert. Next four threaded compression bolts 93 are attached to the bottom compression plate by screwing the ends of the bolts into the plate. The bottom current collector is then placed on top of the compression plate in between the bolts. The top and bottom current collectors 91, 107 form the electrical interface to the outside electrical circuit. They collect the electrical current from the top of the stack, allow it run through the electrical load, and then distribute it back to the bottom of the stack. The next items to go

into the assembly are the fuel cells themselves. Any number of cells 85 may be placed in the stack but 10 or 50 cells are normally employed. The cells are aligned so that their gas inlet and outlet tubes 69 and 73 are aligned on top of each other respectively. After the final cell is placed on the stack, the top current collector 91, and top compression plate 99 are put in place. The four threaded compression bolts 93 fit through the opening in the top compression plate and four nuts 87 are threaded into place. The assembly is then tightened down. The compression force applied by the four threaded rods and nuts does not have to be exactly controlled. This is because the force is not being used to make the seals within the MEA enclosures. The seals have been made earlier with the glue. The force from the compression of the stack is used only to provide planar contact between the cathode screen 67 and cathode of each cell. After good contact has been made any additional force is taken up by enclosure because the cathode screen 67 overlaps the edge of the enclosure. The height that the cathode electrode protrudes above the enclosure is controlled by the thickness of the enclosure sealing lip. This limits the compression of the MEA. Overcompression of the MEA resulting in deformation that can lead to cell failure has been a problem with all previous stack designs to date. The compression on the anode side of the MEA is controlled as well. The height of the MEA enclosure and the thickness of

the anode wire screen 79 control the compression of the anode portion of the MEA during the endplate attachment step. The MEA is compressed only enough to create planar electrical contact between the anode and cathode wire screens and no more. The next steps are to connect the hydrogen gas distribution system to the stack.

The gas distribution system consists of two external manifolds 95, 105; one distributes the hydrogen gas into the stack 105 and one collects the air that must be purged from the MEA enclosure. The fuel cell will not start to function until the oxygen and nitrogen in the air have been eliminated from the anode electrode region. The hydrogen manifolds are hollow tubes whose ends have been block by threaded screws and into which small holes have been drilled at regular intervals. Into these small holes, are placed small interface tubes 97. The small interface tubes have a larger outer diameter than the holes so there is an interference fit which seals the tube into the hole. Plastic connection tubes form the joint between the manifolds and the MEA enclosure inlet and outlet tubes 69 and 73. Large inlet and outlet tubes 101 and 109, respectively, are placed in the manifolds to get the hydrogen gas into and the air out of the manifolds. The manifold diameters are sized such that the total interface tube area is less than 1/10 of inner diameter area of the manifold to prevent any flow induced pressure drop inside the manifold itself.

The assembled SIM stack 113 is shown in Figure 8B.

The operation of the stack will now be described. A pressurized gas cylinder (not shown) with a regulator attached is connected to the hydrogen inlet manifold. The operating pressure of the stack is nominally 2 psig but can go as high as 10 psig. The gas cylinder valve is opened pressurizing the inlet manifold, the anode area of each cell, and the exhaust manifold. The cathode screens also provides electrical contact to the cathode of each cell allowing continuity between that cell and cell below it in the stack. The screens also allows the maximum amount of area to be open to the air. The cathode electrode consumes oxygen from the air and rejects the water that forms in the electrochemical reaction that generates the electricity. A second valve (not shown) connected to the exhaust manifold outlet tube 97 is opened briefly allowing the trapped air in the anode area of the stack to be purged along with some of the hydrogen from the cylinder. The second valve is closed and the pressure now builds up again in the stack. In each anode area of each cell the hydrogen begins to oxidize providing electrons to the external electrical circuit. The stack is now activated and will show a high voltage called an open circuit voltage. But, no current will flow until the external circuit is connect. Once the external load is connected, the cathode side of each cell will begin to reduce oxygen from the air. Each cell in the stack

provides the electrical current for the cell below it. The final cell at the bottom of the stack provides the current to the external circuit which is then returned through the load to the top cell in the stack. The load resistance determines how much current will flow from the stack to the external circuit. The lower the load resistance the more current will flow. The oxidized hydrogen from the anode now begins to flow across the membrane in each cell and join with the reduced oxygen from the air to form water. The stack is now self regulating. The stack will consume only as much hydrogen as necessary to satisfy the current which is determined by the external circuit resistance. The cathode electrode will consume oxygen from the air as needed to keep the current flowing and will reject the water that is formed either as vapor or as liquid droplets.

The next item to be discussed is the shutdown of the stack 113. First the load is disconnected from the stack stopping the current flow. The valve on the pressurized cylinder is turned off. The pressure is then released from the system by opening the purge valve attached to hydrogen exhaust manifold. The cylinder is disconnected from the input hydrogen manifold. The open circuit voltage will persist on the stack as long as their is a concentration of hydrogen fuel is the anode area of each cell. Oxygen and nitrogen from the air will diffuse in through the connections to the hydrogen manifolds. As oxygen

enters the anode area it combines with the remaining hydrogen on the anode electrode surface to form water. As the hydrogen is consumed this way, the open circuit voltage fades to zero.

The SIM design is primarily aimed at passive air flow operation. The second wire cloth on the cathode 65 (Figure 7A), is custom tailored to this particular application. The stack is designed to be operated laying on its side resting on the edges of the top and bottom compression plates. As the stack operates the waste heat from the operation will generate a convective air flow that will rise through the groves in cathode screen 65. Even though the ends of the groves are blocked there is not a seal at any point and the air can still go through the wire cloth layers. The flow resistance of the wire cloth on edge is minimal for the short distances involved. The most important advantage of this cell design is its low cost; it has eliminated all the costly machining operations which were required to form the hydrogen and air gas distribution grooves.

Active flow operation is also possible with this design. A fan will be mounted on one face of the stack and will force air through the stack by direct impingement much like the radiator fan in an internal combustion automobile. Separation of air flows will not be possible with this arrangement so high power stacks are not possible with this design.

It is possible to combine the Single In-line MEA

cell approach and the radial air stack into a single hybrid design incorporating the benefits of both. Such a hybrid cell is shown in Figure 9. This fuel cell is a square SIM cell 137 with a radial air design. The plastic MEA enclosure 121 now incorporates an inner frame 120 to form the opening for the central cavity air flow and a center bolt and/or barrel fan. The assembly is exactly the same as the previous Single In-line MEA approach with one exception. The inner frame 120 is attached to the MEA first. This is done by applying a bead of glue 125 to the inner lip of the radial MEA 127. The glue is cured using ultraviolet radiation or heat to fuse the inner frame to the MEA forming a gas tight seal. The MEA with the inner frame 120 already attached is then joined to the enclosure 121. The cathode screen 117 and endplate 135 have a square form but are treated and joined the same as in the straight SIM design. The cathode screen 115 is shown with a radial slot pattern which mimics the radial grove pattern of the bipolar plate 17 of Figure 2. A single assembled radial SIM cell 137 is shown in Figure 9B.

The form of fuel cell stack employing this hybrid cell design can either be a single center bolt compression or the four bolt peripheral compression approach. The single center bolt compression scheme will generate a smaller lighter stack but a peripheral bolting scheme will allow for a more simple barrel fan design. There is an cost advantage to a square design

over a circular one due to the elimination of MEA waste. The MEA components are fabricated in a square format which results in waste when circular forms are cut.

The assembly of either of form of hybrid stack is similar to the SIM stack and the operation of the Radial SIM hybrid stack design is also similar. This includes the three types of air flow depending on whether passive air, active air flow with fan/enclosure, or active air flow with incorporated barrel fan is employed.

In accordance with the present invention, a stack assembly of individual fuel cells is assembled. Each of the fuel cells that goes into the stack may be made up of six components. The electrochemically active component that creates the electricity is called the Membrane Electrode Assembly ("MEA").

Referring to Figure 10A, one type of MEA 207 used in one embodiment of the invention is shown which consists of five pieces. As is shown in Figure 10C, the innermost piece within the MEA is the fuel cell membrane 7. The anode catalyst layer 202 and cathode catalyst layer 203 are applied to either side of the membrane creating an electrode/membrane/electrode sub-assembly 204. The catalyst layers are run through several processes to intimately bond the layers to the membrane. The cathode catalyst layer 203 is slightly smaller in both dimensions than the membrane itself. The size difference between the cathode catalyst layer

203 and the fuel cell membrane 7 creates a small band of exposed membrane which runs around the outside of the assembly. This area will be used as a bonding area in assembly steps. An anode carbon cloth 5 and cathode carbon cloth 9 are then bonded to their respective catalyst layers in a high-pressure lamination step at elevated temperature. The cathode carbon cloth 9 preserves the size difference between cathode catalyst layer 203 and the fuel cell membrane 7. The anode carbon cloth 5 and the cathode carbon cloth 9 are both electrically and thermally conductive. In addition, both layers will reject liquid water but are porous to water vapor, hydrogen fuel gas and oxygen from the air. The finished MEA 207 is shown in Figure 10A.

Referring now to Figure 11A and 11B, after the MEA 207 has been assembled, it is bonded to a part called a MEA enclosure or surround 210. The MEA Surround 210 is a hollow structure with an open top face which supports and contains the MEA 207 and the metal anode screen 209. A small band of exposed membrane on the MEA 207 is glued to the lip on the open top face of the surround 210. The MEA surround 210 design allows the cathode carbon cloth of the MEA 207 to project through the open top face allowing oxygen and electrons access to the cell. The MEA surround 210 also isolates the anode carbon cloth 5 of the MEA from the atmosphere and provides it with fuel gas to sustain the electrochemical reaction. In order to

provide a cavity for the fuel gas to reside within the cell the anode screen 279 is sandwiched between the MEA assembly 207 and metal cell endplate 8. The presence of the metal anode screen 209 electrically connects the anode side of the MEA to the cell endplate 288. This electrical connection allows electrons to flow from the anode of this cell to the cathode of cell below it in the stack. The MEA surround 210 is glued to the edge of the cell endplate 208 to form a seal. The glue should be chemically compatible with fuel cell operation and it not form a stressed bond because of excessive shrinkage of the joint. Several types of glue will form the joint adequately. The MEA surround 210 and cell endplate 208 have four holes, one in each corner. These holes are connected to distribution ducts 213 within the MEA surround 210, which run along the sides of the surround. The holes allow the fuel gas to be fed into the cell from above or below and the ducts distribute the fuel gas along the periphery of the MEA. This design insures even utilization of the anode surface by guaranteeing the even distribution of the fuel gas into the cell during operation. The final step in the assembly of the cell is to glue the rubber cathode air spacers 211 to edges of top face of the MEA surround 210. The cathode air spacers 211 contain gas pass-thru ports 214 which line up with the holes in the top face of the MEA surround 210 and the cell endplate of the cell above it in the stack. When compressed the

rubber cathode air spacers 211 form a cell-to-cell seal for the fuel gas connection. The cathode air spacers 211 also functions as a structural connection, which compensates for finished cell thickness variations. A cathode air fin 212 is placed between the cathode air spacers 211 and rests against the cathode cloth 9 of the MEA, which is projecting through the top face of the MEA surround 210. The cathode air fin 212 allows oxygen to access the cathode by passing along the fin grooves and provides an electrical pathway for the electrons from the cell above to reach the cell. When the cell is compressed in the stack the cathode fin 212 comes in contact with the cell endplate 288 of the next cell in the stack. The cathode air fin 212 can either be made from a solid piece of thin metal or it can be perforated to increase the oxygen access to the cell. The cell is now complete and the finished cell assembly 215 is shown in Figure 11A.

In a finished stack of fuel cells, there is one cell in the stack whose assembly may be different from all the other cells. For example, the cell that occupies the bottom cell slot in the the stack may be assembled using the bottom current collector 16 (Figure 12) as the cell endplate. Despite this difference, however, the bottom cell assembly is similar to all other cells. Each finished assembled fuel cell 15 may be tested individually. Because each cell is a complete stand-alone entity, it can be

tested individually and repaired or discarded if necessary. This is advantage for efficient manufacturing because it prevents assembling a stack with defective cells. After the testing is complete, the cell may be placed into a stack.

Referring to Figure 12, a stack assembly 220 is shown. The stack components are symmetrical on top and bottom. To begin the assembly process, a compression plate 218 is placed on a flat surface. The compression plate 218 has holes drilled for the insertion of threaded rods, which will connect the top and bottom Compression plates together mechanically. The compression plate is metal structure whcih evenly compress the finished cell assemblies 215 in the center of the stack. The compression plates 2318 must be thick enough to not bend under the mechanical load. The compression plate 218 is preferably a structural component and does not perform an electrical function. Next, a hydrogen manifold 217 is placed onto the center of the bottom compression plate. The hydrogen manifold 217 provides a way of injecting the fuel gas, hydrogen, into the stack 220. A series of grooves are located in the top face of the manifold 217 which allow the gas to flow across the face of the manifold. The grooves only form three sides of a duct. The fourth side of the duct is formed by the current collector 216. The top current collector 216 is glued to the face of the hydrogen manifold 217 forming a sub-assembly, prior to being placed into the stack

sealing the grooves. The bottom current collector 216, already part of the bottom fuel cell, is glued to the face of the bottom hydrogen manifold 217. There are holes in the current collector 216 to allow the gas to flow from the hydrogen manifold 217 to the cells in the stack. Two holes on the side face of hydrogen manifold 217 form injection ports and connect to the grooves. The top and bottom hydrogen manifold 217 are identical in design and size. Typically, the top hydrogen manifold 217 is used to inject the hydrogen gas from a storage cylinder and the bottom hydrogen manifold 217 is used to form a recirculation loop . Many different groove patterns are possible to distribute the hydrogen gas across the stack and form the recircuation loop.

Referring to Figure 19, one particular groove pattern is shown. Injection port 238 of the top hydrogen manifold 217 connects the fuel gas source to the stack; the main flow of gas into the stack flows by the venturi connection groove 240. The recirculation loop is form by connecting injection port 239 of the top hydrogen manifold 27 via an external tube (not shown) to the bottom hydrogen manifold injection port 239. As the stack consumes hydrogen, the venturi connection groove 240 between injection ports 238, 239 draws hydrogen gas from the bottom of the stack due to the drop in pressure in the venturi opening. The bottom hydrogen manifold injection port 239 is capped offwith normally closed

valve and used as purge port. This purge is done to at beginning of stack operation, when the hydrogen gas is first injected, to clear residual air from anode cavities of each cell in the stack. The normally closed valve, which is connected to injection port 239 of the bottom hydrogen manifold, is opened to allow the air from the cell cavities to exit the stack.

Referring again to Figure 12, the tested individual fuel cells are stacked one-by-one on top of the bottom hydrogen manifold 217 and current collector 216. Finally the top current collector plate 216 hydrogen manifold 217 is placed on the top of the individual stacked fuel cells 215. The top compression plate 218 is the final piece of the stack. Four threaded rods 219 are screwed into the bottom compression plates. The number of these rods will depend on the length and width of the stack. Using nuts on the threaded rods 219, the top compression plate 218 compresses the stack to the required height. At the reqired height, the hermetic cell to cell gas connections have been made due to the compression of the cathode air spacers 211. Also at the required height, a low resistance electrical connection has formed between each cell due to the contact of the cathode fin 212 to the cathode cloth 9 of the MEA assembly 207 and the cell endplate 288 of the cell above it in the stack. The top cell in the stack makes a hermetic seal and electrical contact to the top Current Collector The stack is now complete.

Referring to Figure 13, the top and bottom current collector contain connection tabs which project out from the sides of the finished stack assembly 220. The injection ports 238, 239 of the top and bottom hydrogen manifold are easily accessible for connection to a fuel gas reservoir. The stack is designed for passive airflow operation. The oxygen from the surrounding air diffuses into the center of each cell along the fin openings, are visible along the side of the stack. No air containing oxygen is forced into the center of the stack. The stack can be turned on its side, letting the heat of fuel cell operation form convection currents, increasing the air/oxygen access to the cells. This type of stack is primarily a low power design. The availability of the oxygen limits the power output from the stack.

A higher power stack demands active airflow to force air through the stack to deliver more oxygen to the cells. In addition, a higher power stack also must reject the waste heat efficiently to prevent overheating and power loss. The fuel cell architecture depicted above can easily be adapted for active airflow and several different cooling schemes. For example, as shown in Figure 14A and 14B, a finned cell assembly 223 may be used. The cell endplate has been extended beyond the edges of the MEA surround 210. This is called a finned cell endplate 228. This cell endplate is preferably made from a 316L stainless steel clad aluminum which has superior

thermal, electrical, specific density characteristics to plain 316L stainless steel. The cell assembly is nearly identical to the non-finned version. However, one difference is that the threaded rods 219 pass through every cell endplate, using the pass-thru holes provided. Another difference is that two air guides 221 are used for every cell and are placed along the edges of the MEA surround 210 as shown. The air guides 221 form three sides of an air duct. The fourth side of the duct will be provided by the cell endplate of the next cell in the stack. Once the stack is assembled, air can now only enter and exit the the cell in the gaps between the air guides 221 and the MEA surround 210.

The stack assembly of the finned cell stack shown in Figures 15 and 16 is nearly identical to the non-finned stack.

With a properly designed enclosure, it is now possible to provide two active airflows to the stack, which do not interact with each other. This dual flow non-interacting flow arrangement is called a dual separated airflow or DSA. The first active airflow is to provide oxygen to the cells within the stack. This airflow will have a variable flow rate based on a complex algorithm whose inputs are the current being generated by the stack, the humidity of the incoming air, and the temperature of the stack. The stack temperature influences the water removal rate to such an extent that the oxygenation air flow at high

current levels, high temperatures, and low incoming humidity must be decreased to prevent removing too much water. The second air flow will cool the stack. It will be proportional only to the temperature of the stack. The hotter the stack is the more airflow that will be directed over the fins. The fins, which are part of the finned cell endplate 222 are stamped from 316L stainless steel, clad aluminum. The stamping process will impart a stepped ridge pattern into the fins to prevent the formation of laminar flow along the fin direction. An enclosure for one of finned stack is shown in Figure 17.

In Figure 17, the finned fuel cell stack, has been rotated 90 degrees and inserted into a fuel cell stack chamber 327. The fuel cell stack chamber 327 is a part of a multi-chambered enclosure 325. A large cooling air barrel fan 329 mounted on the rear face of the multi-chambered enclosure 325. The cooling air barrel fan draws air from an cooling-air collection chamber 326, which in turn, draws air across the upper fins 331 and the lower fins 330. Fresh air will enter the fuel cell chamber 327 from openings which are located along the front face of the multi-chambered enclosure 325. Also mounted on the front face of the multi-chambered enclosure 325 is a smaller oxygenation-air barrel fan 332. This fan draws oxygenation air through each cell using the ducts formed by the finned air guides 221 which are shown in dashed outlines on the top of the finned fuel cell

stack. The air guides 221 keep the two airflows from interacting with each other. Oxygenation-air going into the stack is drawn from an oxygenation-air inlet plenum 330, which is inserted through the cooling-air collection chamber 326. The oxygenation-air inlet plenum is a walled off from the cooling-air collection chamber 326 and the ends of the plenum are open to the ambient air. The two fans can now draw whatever air their respective operations call for to maintain the fuel cell operation without having one airflow influence the other. Other cooling schemes are also possible. Water cooled plates may be added to the stack where the ambient conditions or the stack power output does not let air cooling reject enough energy. Two slotted water-cooled non-electrically conductive plates 335 cover the ends of the fins and they are in thermal contact with the fins through the use of thermally conductive grease. This arrangement is shown in Figure 9. The fuel enclosure can be simplified to a single chamber 337. The oxygenation airflow works the same as in Figure 17. Two water injection ports, an inlet 338 and an outlet 334, are depicted. Not shown are the water pump, heat exchanger and heat exchanger fan. The cooling subsystem in this case is considerably more complex than the air-cooled system.

Although the invention has been disclosed in connection with the embodiments discussed herein, it will be apparent to one of ordinary skill in the art,

that various modifications to these embodiments may be made without departing from the scope of the invnetion as defined by the following claims.

CLAIMS:

What is claimed is:

1. A fuel cell stack assembly comprising:

a first cell comprising,

a membrane electrode assembly having a proton exchange membrane located between a cathode layer and an anode layer,

a gas distributor engaged to said membrane electrode assembly to supply gas from a gas supply means to said anode layer, said membrane electrode assembly and said gas distributor forming an anode side and a cathode side of said first fuel cell;

said first fuel cell being stackable upon a second fuel cell and forming a space therebetween for the passage of oxygen containing gas therein; and

said first and second fuel cells being capable of producing an electrical current when gas is supplied from said gas distributor to said anode.

2. The fuel cell stack assembly of claim 1 wherein the cathode side of said first fuel cell comprise a plurality of passages for allowing the oxygenated gas to pass therethrough and over said cathode layer.

3. The fuel cell assembly of claim 2 wherein said gas distributor is configured to supply gas to an outer edge of said anode layer when said gas flows

from said outer edge of said anode layer over said anode layer.

4. The fuel cell assembly of claim 3 wherein said gas distributor comprises an enclosure which surrounds the outer periphery of said anode layer.

5. The fuel cell assembly of claim 4 wherein said enclosure comprises one or more openings facing towards said anode layer to supply gas over said anode layer.

6. The fuel cell assembly of claim 5 wherein said enclosure comprises a gas inlet port and a gas outlet port leading to said one or more openings.

7. The fuel cell assembly of claim 6 wherein said gas inlet port is in fluid flow relationship with said gas supply means.

8. The fuel cell assembly of claim 7 wherein said enclosure comprises a gas distribution port, said gas distribution port being positioned to supply gas to a second enclosure on said second fuel cell when said first fuel cell is stacked with said second fuel cell to supply gas to the anode layer of said second fuel cell.

9. The fuel cell assembly of claim 3 wherein said gas distributor comprises a plate having a side facing said anode layer and one or more openings for allowing said gas to flow over said anode layer.

10. The fuel cell assembly of claim 3 wherein said plate comprises a plurality of grooves on said side facing said anode layer.

11. The fuel cell assembly of claim 10 wherein said first fuel cell and said second fuel cell comprises a hole located transversely therethrough for allowing oxygenated gas to flow therethrough.

12. The fuel cell assembly of claim 11 further comprising a fan positioned to force air through said hole.

13. The fuel cell assembly of claim 8 further comprising a cathode material placed over said cathode layer, said cathode material being configured to allow oxygenated gas to flow therethrough.

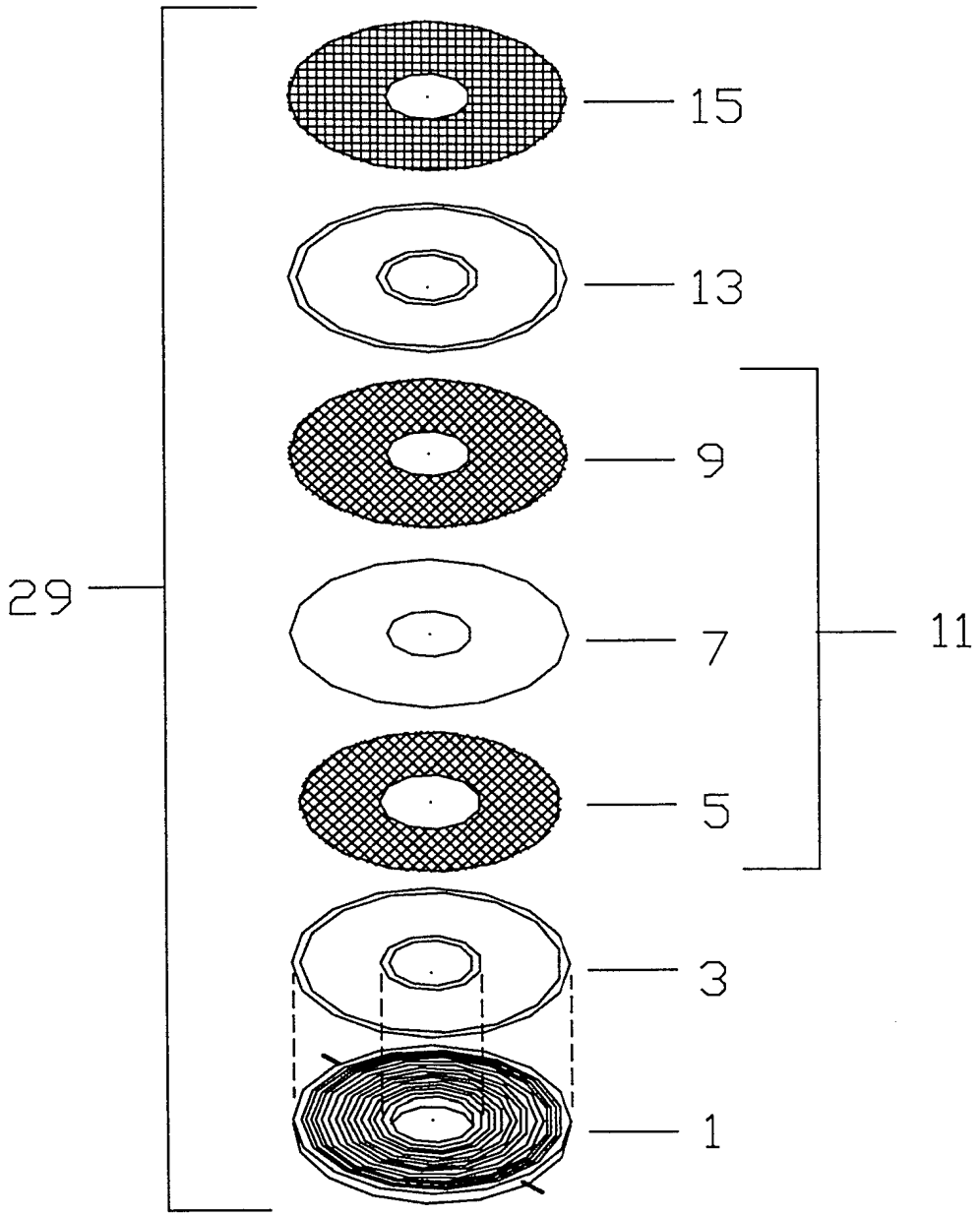


Fig. 1

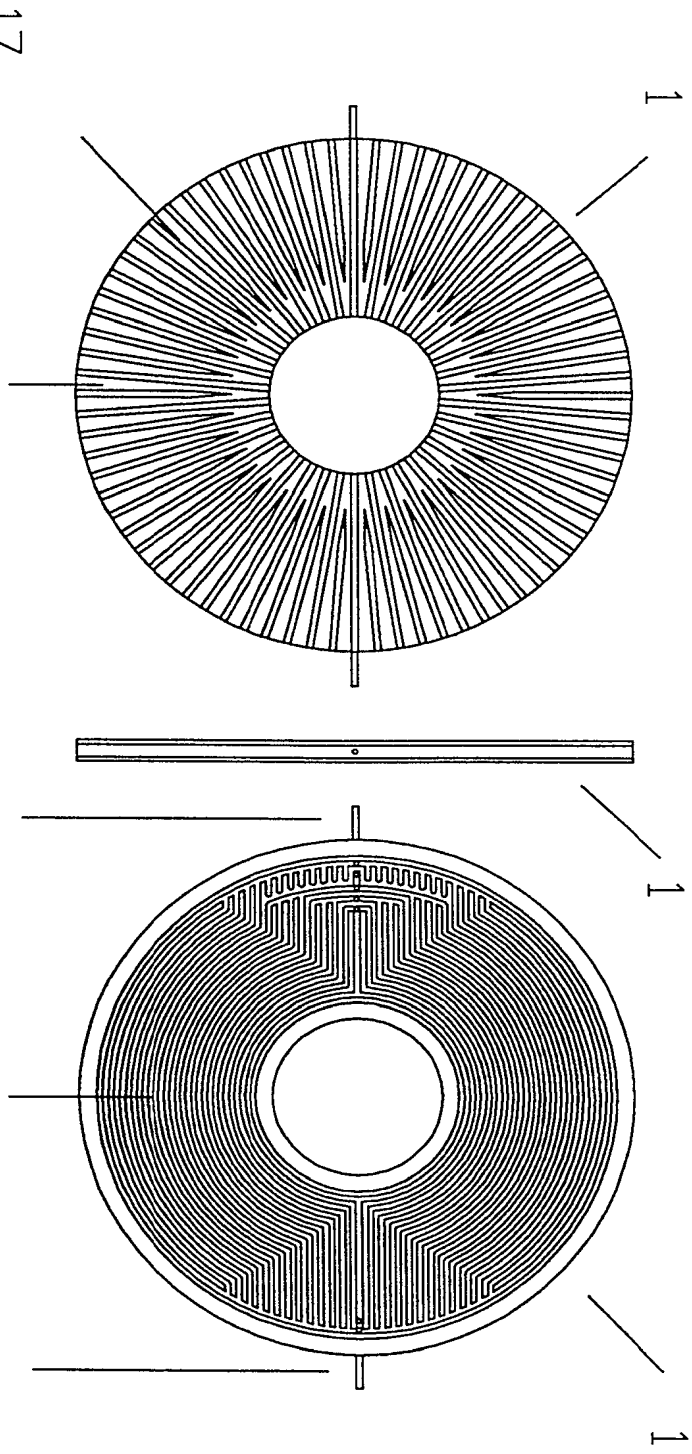


Fig. 2

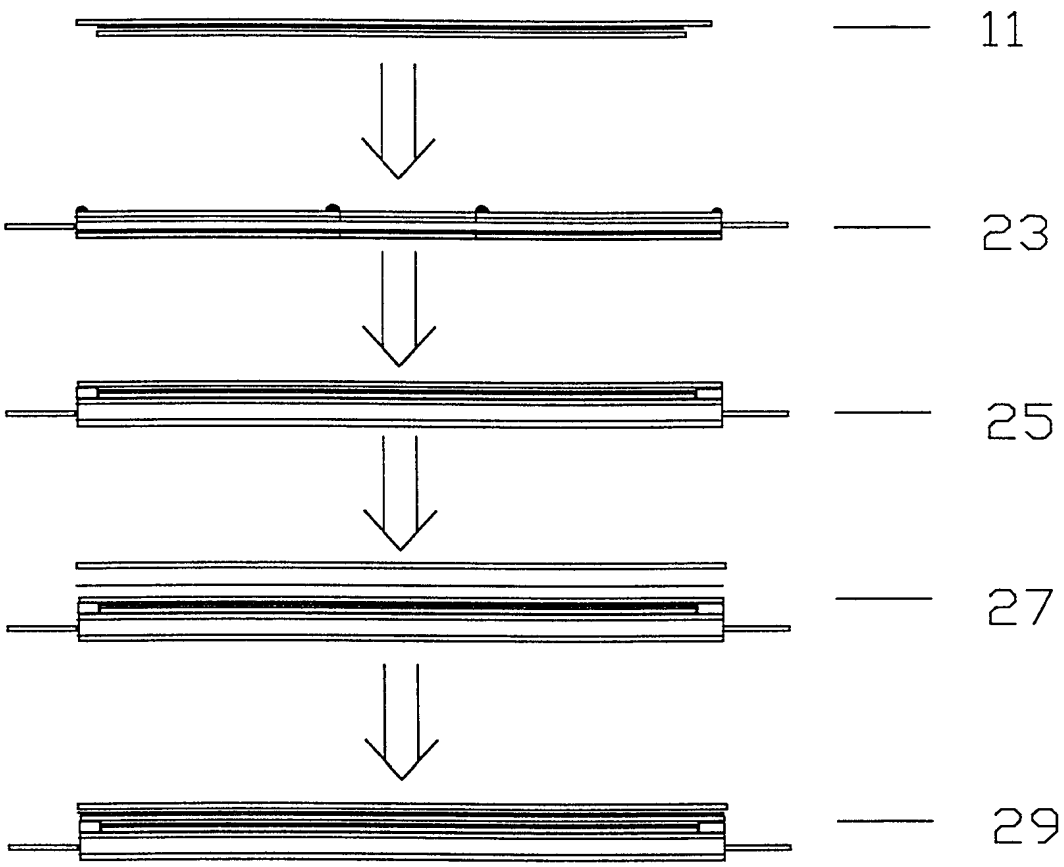


Fig. 3

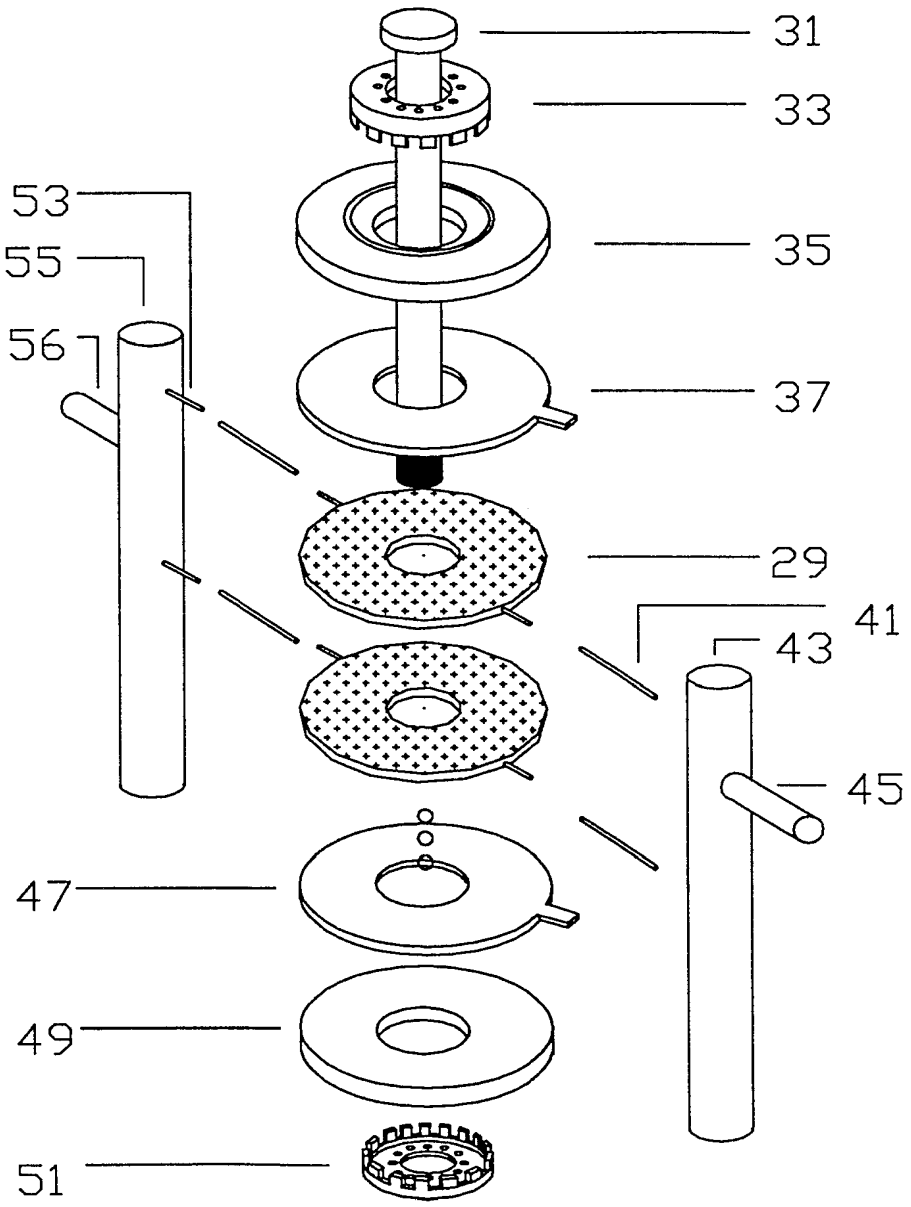


Fig. 4A

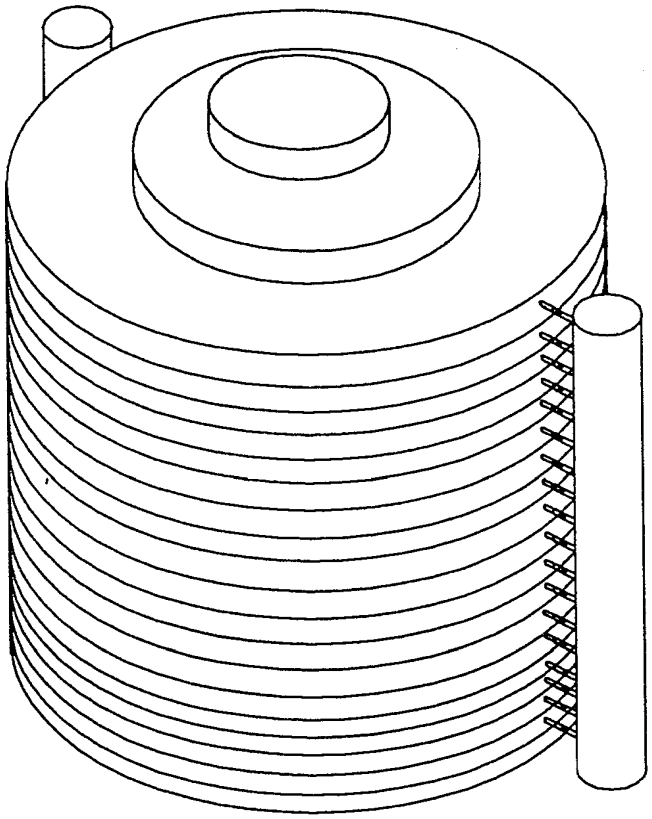


Fig. 4B

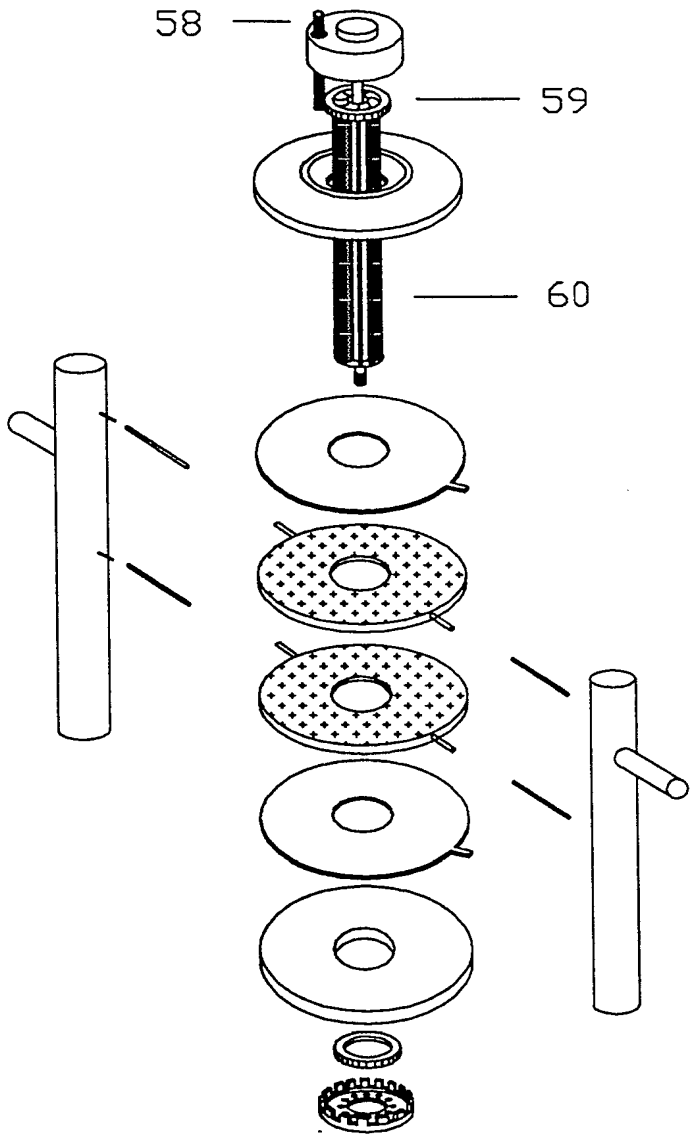
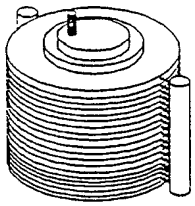


Fig. 5A



ASSEMBLED ACTIVE FLOW RADIAL AIR STACK

FIG. 5B

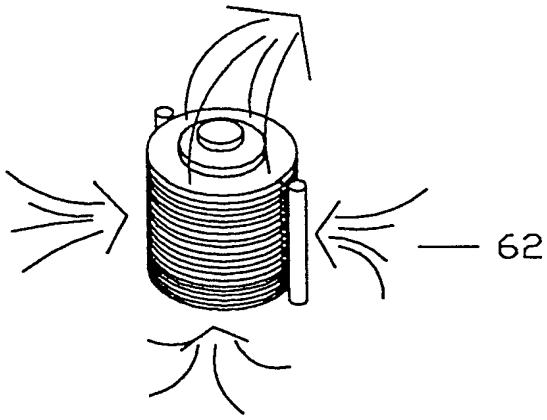


Fig. 6A

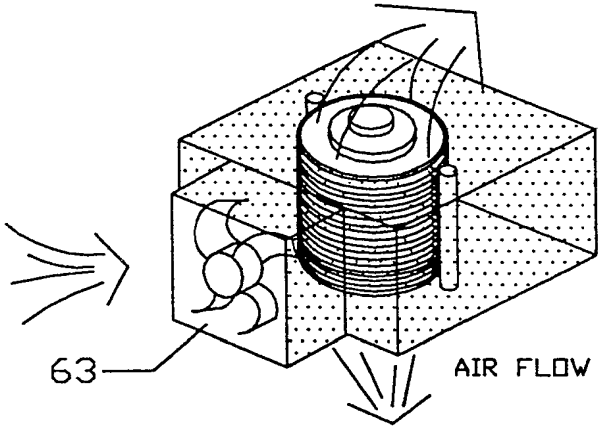


Fig. 6B

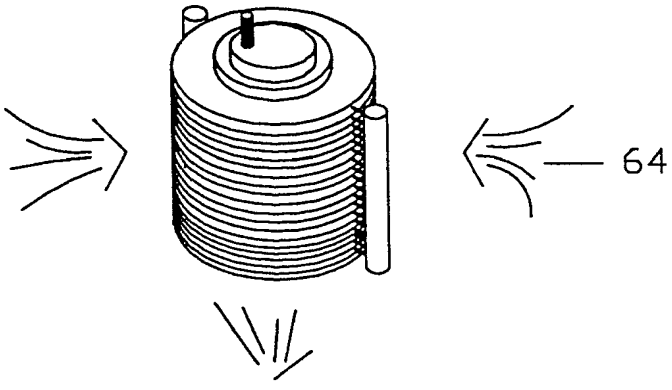


Fig. 6C

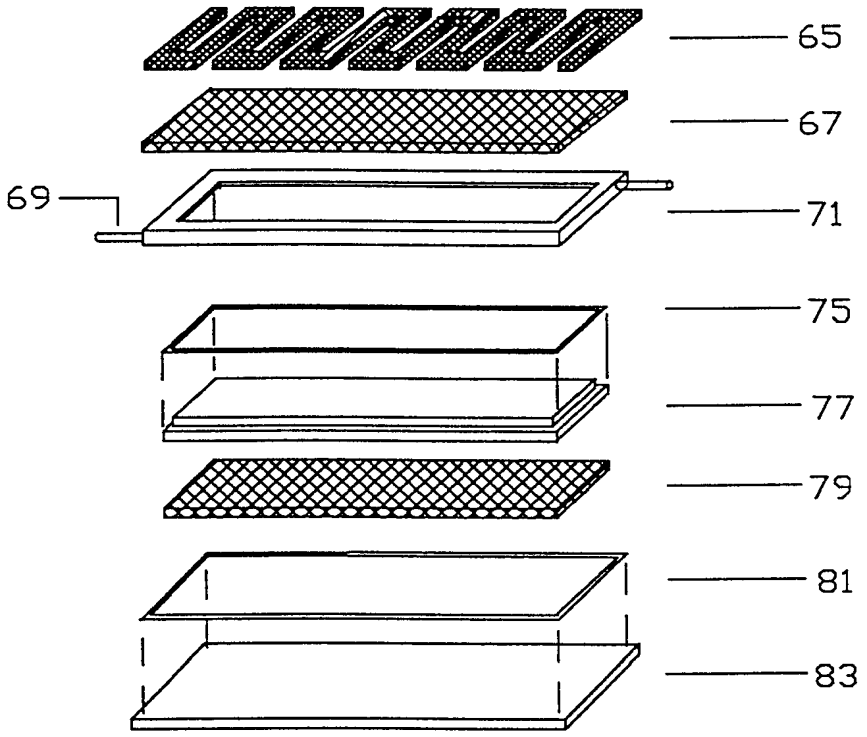


FIG. 7A

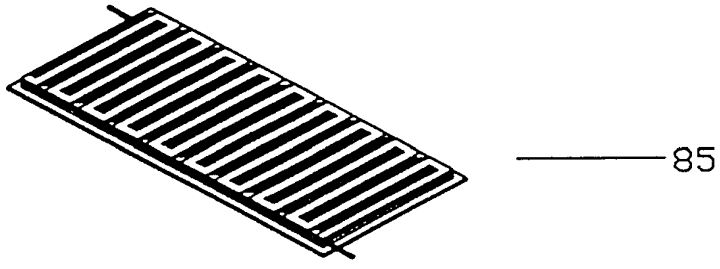


FIG. 7B

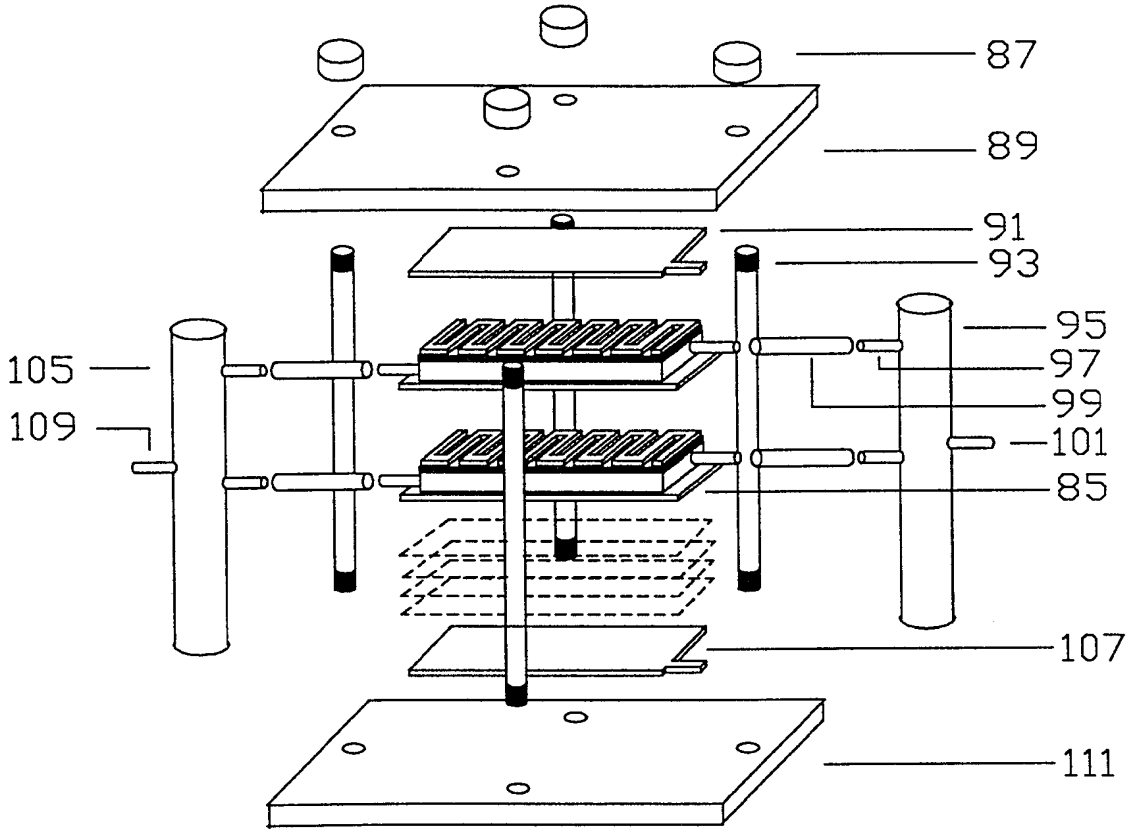


Fig. 8A

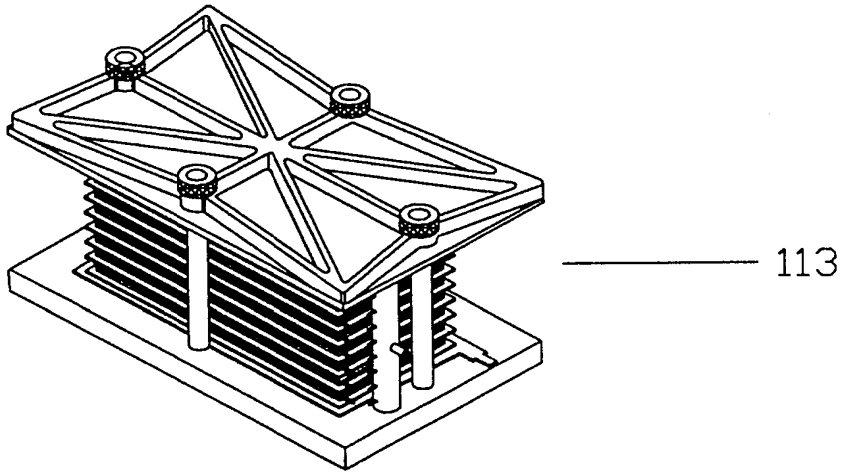


Fig. 8B

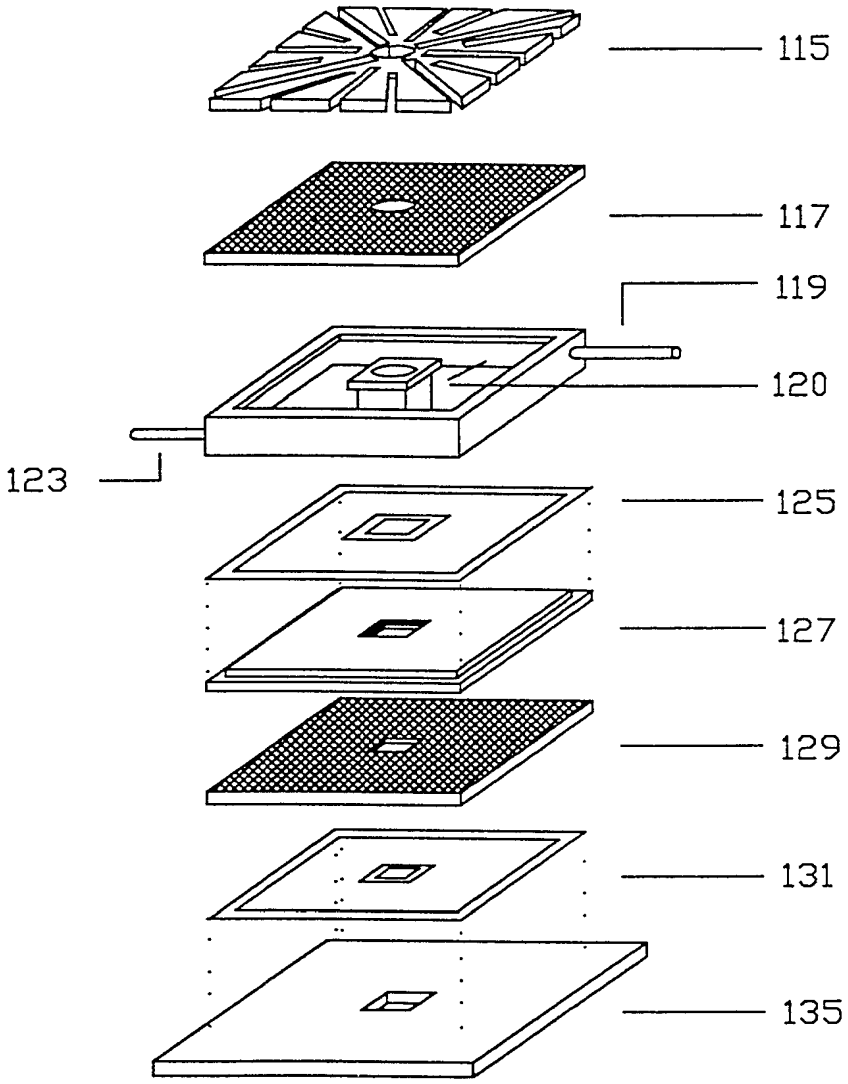


Fig. 9A

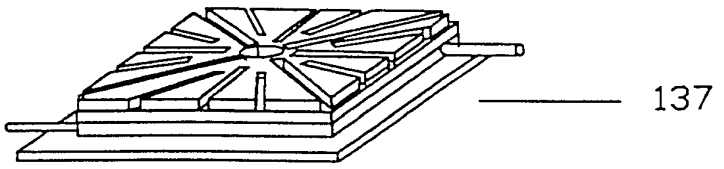


Fig. 9B

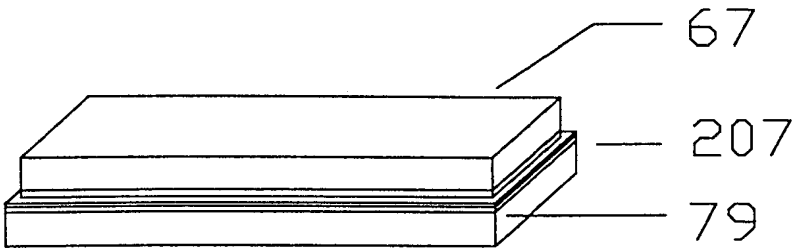


Fig. 10A

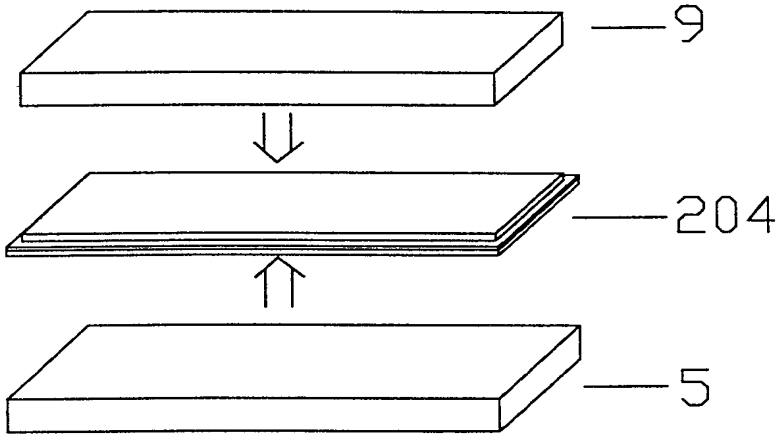


Fig. 10B

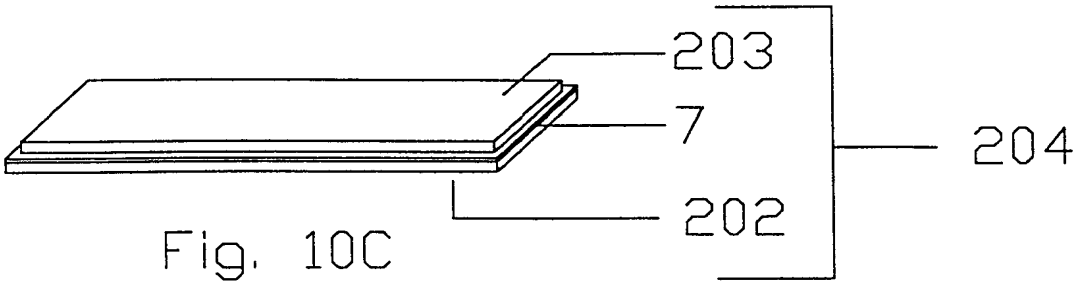


Fig. 10C

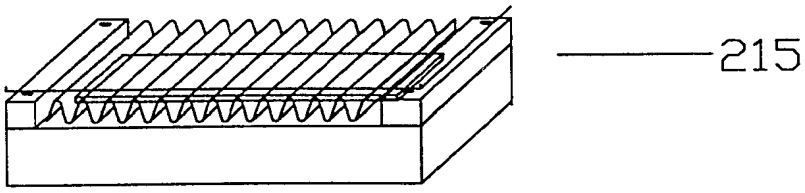


Fig. 11A

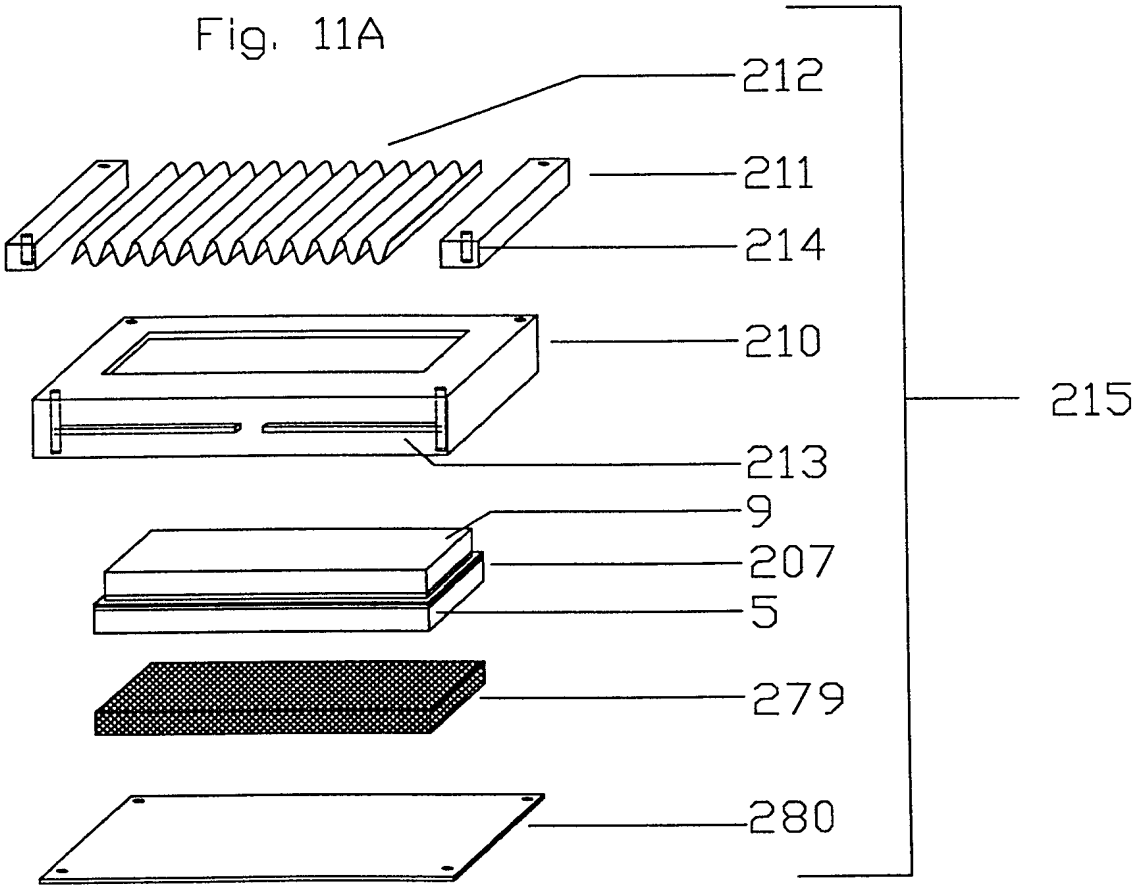


Fig. 11B

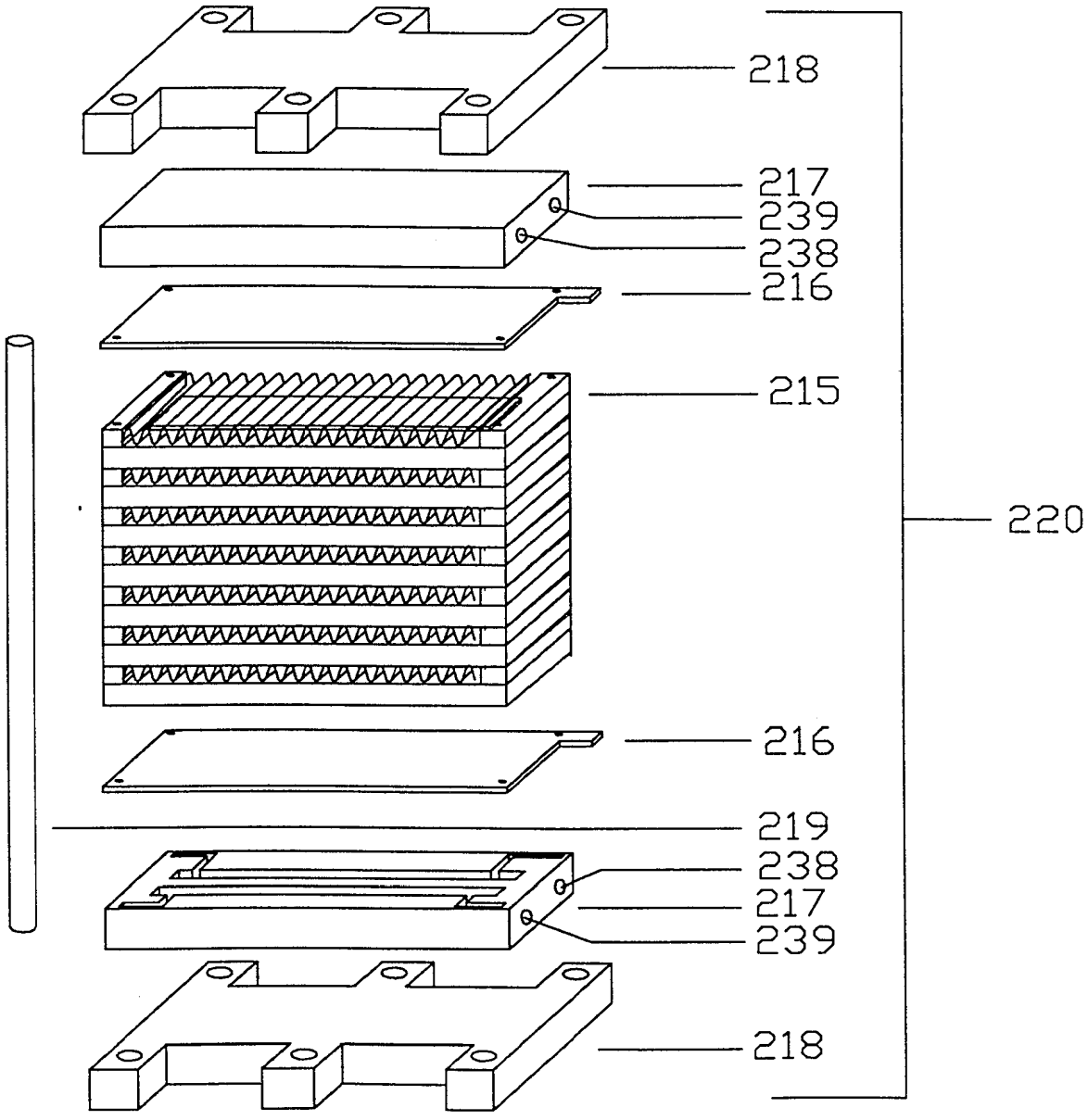


Fig. 12

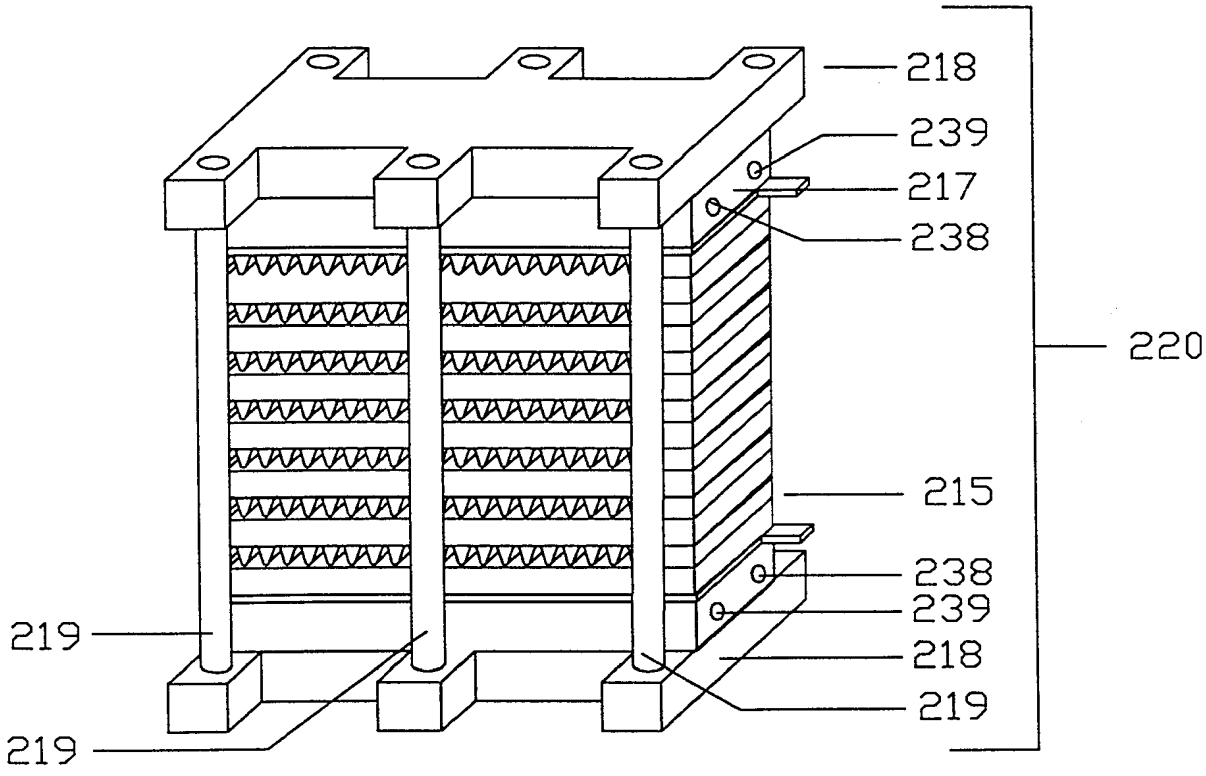


Fig. 13

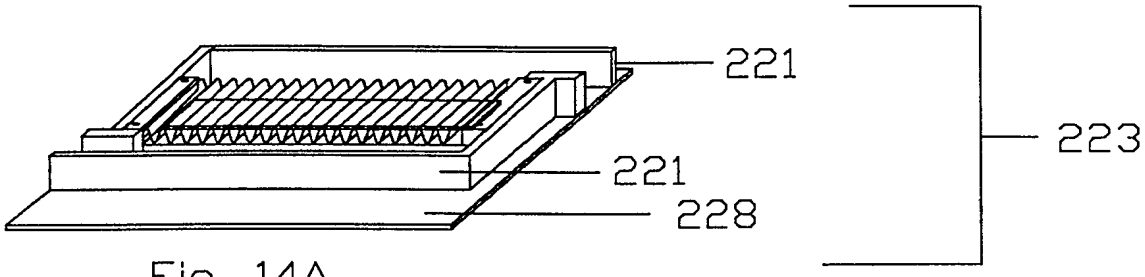


Fig. 14A

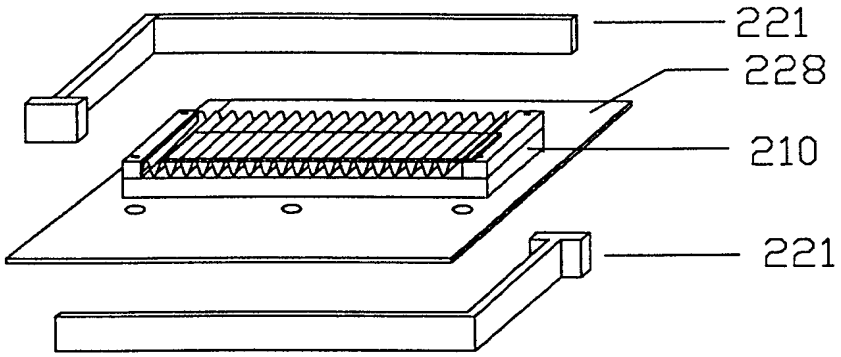


Fig. 14B

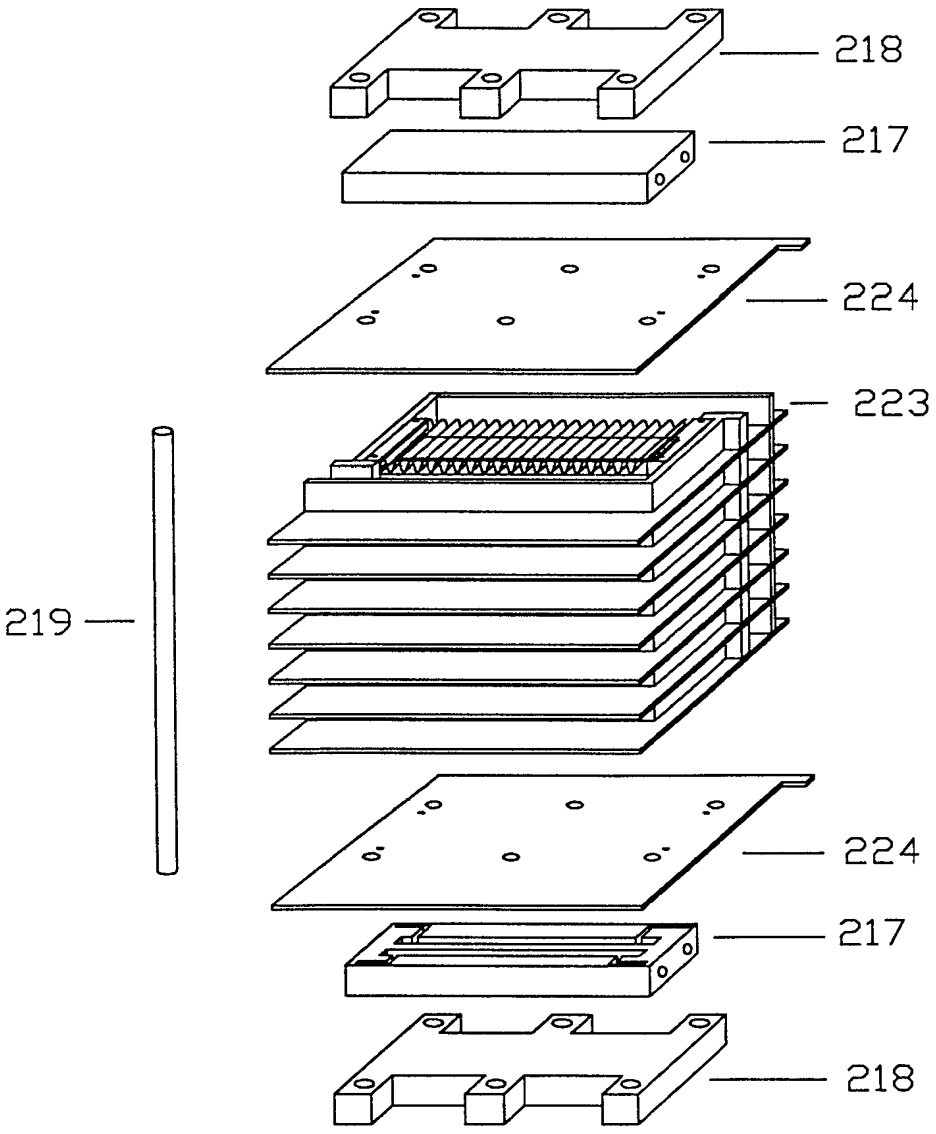


Fig. 15

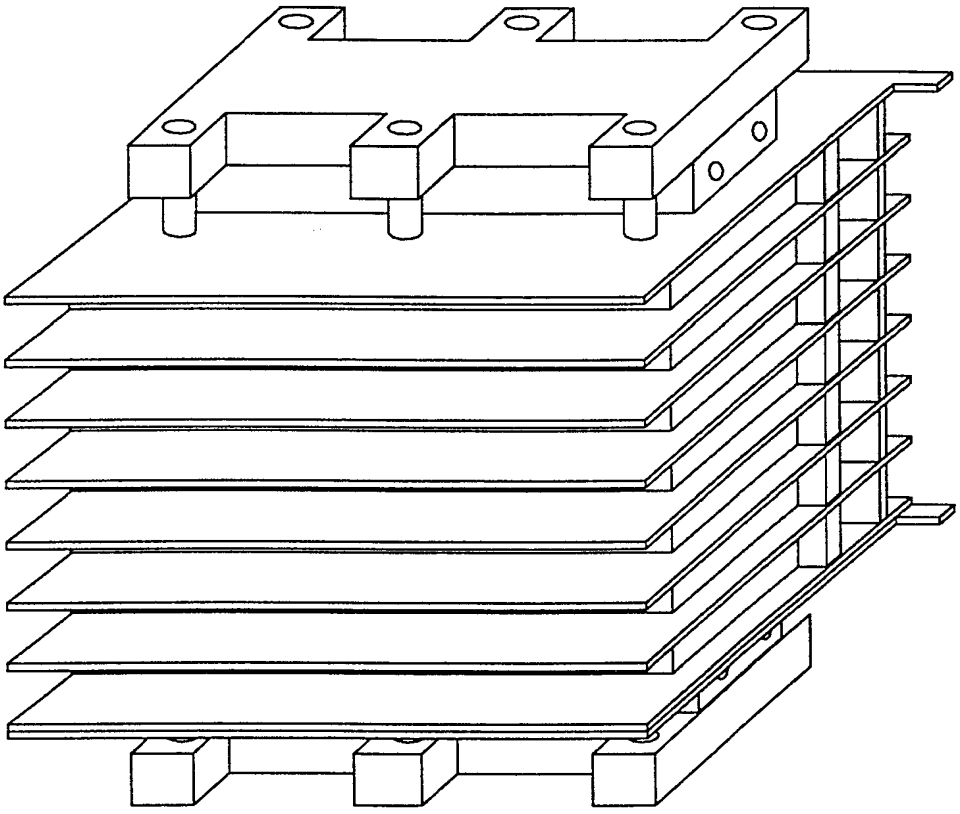


Fig. 16

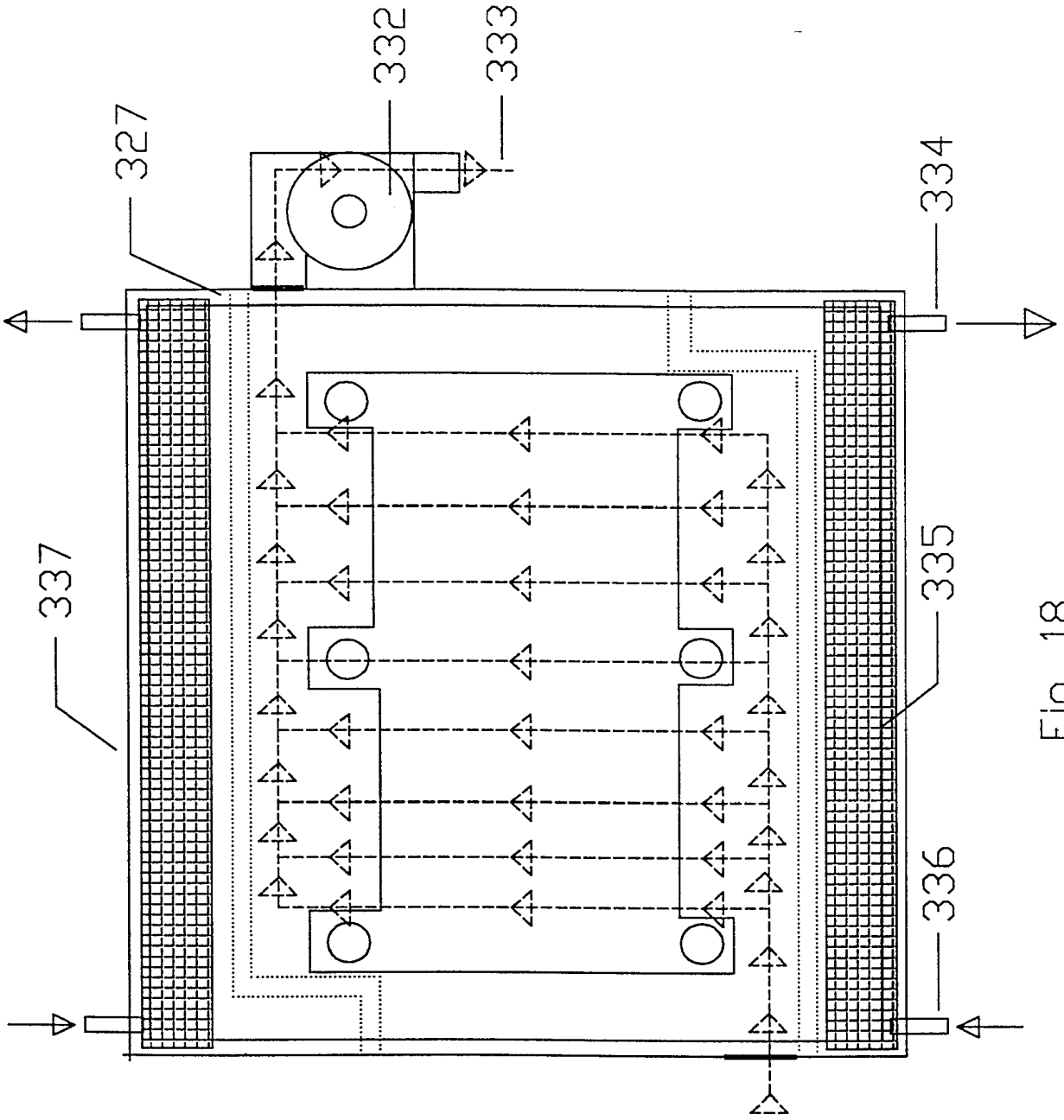


Fig. 18

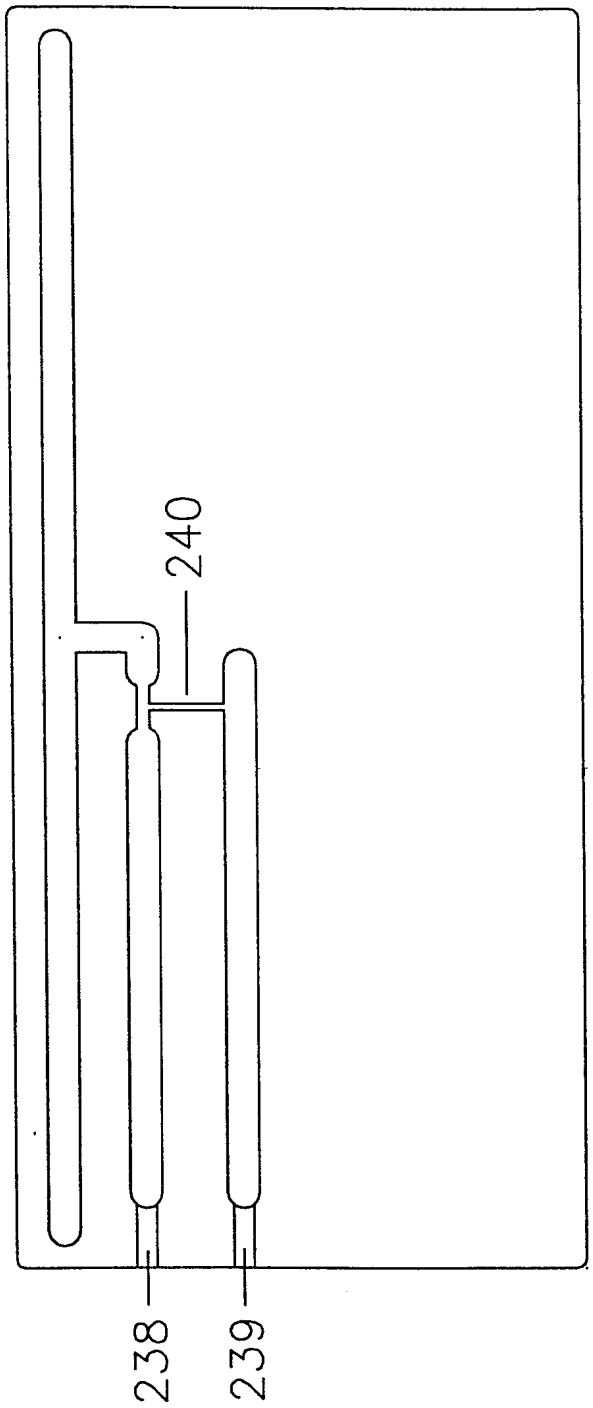


Fig. 19

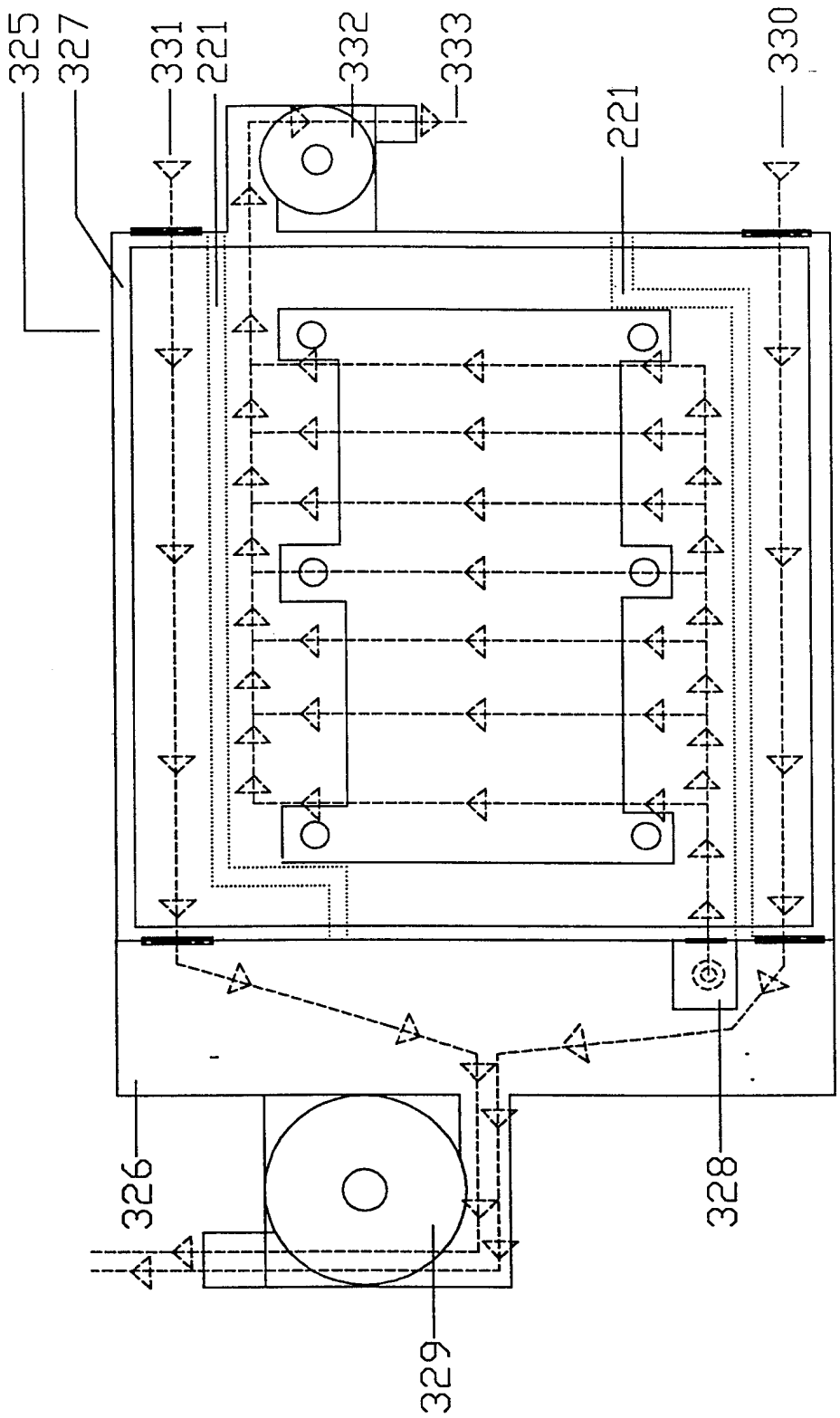


Fig. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/20898

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01M 8/04
US CL :429/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/34, 30

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,288,562 A (TANIGUCHI ET AL) 22 February 1994 (22-02-94), figures 1-5, column 3, line 58-column 4, line 26, examples 1-2.	1-7, 9
A	US 5,571,630 A (CHEIKY) 05 November 1996 (05-11-96).	1-13
A	US 5,486,428 A (GARDNER ET AL) 23 January 1996 (23-01-96).	1-13
A	US 5,418,079 A (DIETHELM) 23 May 1995 (23-05-95)	1-13
A	US 5,270,131 A (DIETHELM ET AL) 14 December 1993 (14-12-93).	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
04 FEBRUARY 1998

Date of mailing of the international search report
25 FEB 1998

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